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Production and carcass traits of high dairy genetic merit Holstein, standard dairy genetic merit Friesian and Charolais × Holstein-Friesian male cattle

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The increased proportion of Holstein genetic material in the dairy herd has consequences for beef production in Ireland. A total of 72 spring-born male calves (24 Holsteins (HO), 24 Friesian (FR) and 24 Charolais × Holstein-Friesians (CH)) were reared from calfhood to slaughter. Calves were artificially reared indoors and spent their first summer at pasture following which they were assigned, on a breed basis, to a factorial combination of two production systems (intensive 19-month bull beef and extensive 25-month steer beef) and two slaughter weights (560 and 650 kg). After slaughter the pistola hind quarter was separated into fat, bone and muscle. Live-weight gain, carcass gain, kill-out proportion, carcass conformation and carcass fat scores were 830, 811 and 859 (s.e. 14.9) g/day, 540, 533, 585 (s.e. 7.7) g/day, 526, 538 and 561 (s.e. 3.0) g/kg, 1.51, 2.18 and 2.96 (s.e. 0.085), and 3.40, 4.25 and 4.06 (s.e. 0.104) for HO, FR and CH, respectively. Corresponding values for pistola weight as a proportion of carcass weight, pistola muscle proportion and pistola fat proportion were 458, 459 and 461 (s.e. 2.6) g/kg, 657, 645 and 667 (s.e. 3.7) g/kg, and 132, 161 and 145 (s.e. 4.1) g/kg. Compared with the intensive system, animals on the extensive system had a lower ($P < 0.001$) daily live-weight gain, kill-out proportion and a lower muscle proportion in the pistola. Increasing slaughter weight increased ($P < 0.001$) carcass weight and carcass fat score and reduced the proportion of muscle in the pistola. Allometric regression coefficients for pistola weight on side weight, and total bone, muscle and fat weights on pistola weight were 0.898, 0.755, 0.900 and 1.910

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respectively. It is concluded that HO grew at least as fast as FR but had a lower kill-out proportion. Carcass conformation and fat scores were greater for FR than for HO and muscle proportion in the pistola was lower and total fat proportion was higher. Compared with FR, CH had heavier carcasses, a higher kill-out proportion and less fat and more muscle in the pistola.

Keywords: Breed, carcass traits; cattle

Introduction

The source of calves for beef production in Ireland is the national cow herd of 2.28 million animals, of which 1.13 million are dairy cows (CSO, 2003). Holstein-Friesian sires account for approximately 96% of dairy breed matings on dairy cows. Consequently, almost half of the calves born to dairy cows and over 20% of the national calf crop are sired by Holstein-Friesian bulls (Irish Cattle Breeding Federation (ICBF), 2002). Continental beef breeds sire over one quarter of the Irish dairy herd calf crop (ICBF, 2002). The importation of North American and European Holstein-Friesian genetic material has changed the genetic composition of the Irish dairy herd, from predominantly British Friesian to North American and European Holstein-Friesian (Buckley *et al.,* 2000b). These trends are also evident in other EU countries.

In previous experiments at this Centre, Friesian and Holstein × (Holstein × Friesian) steers (Keane and More O'Ferrall, 1988), and Friesian and Charolais × Friesian steers (More O'Ferrall and Keane, 1990; Keane *et al.,* 1990) were compared but the dairy animals used in these experiments were of much lower genetic merit for dairy traits than those currently produced. Beef breed comparisons need to be undertaken within the type of production systems to which the results are intended to apply (Keane and Allen, 2002) and due to the possibility of genotype × slaughter weight interactions animals must be slaughtered at more than one end point to obtain commercially useful estimates of growth patterns (Keane, More O'Ferrall and Connolly, 1989; Keane *et al.,* 1990; Keane, 1994; Keane and Allen, 1998).

Numerous published reports show that bulls are superior to steers in growth rate, feed efficiency and carcass muscle proportion (e.g. Steen, 1995; Fallon, Drennan and Keane, 2001). While relatively extensive steer beef production systems are dominant in Ireland (Keane and Allen, 1998), a more intensive, commercially relevant, production system based on bulls needs to be evaluated to reflect the renewed interest in this area (Keane and Fallon, 2001; Fallon *et al.,* 2001).

The objectives of the present study were: (i) to compare growth and carcass traits of Holstein, Friesian and Charolais × Holstein-Friesian males, (ii) compare these breed types in two production systems (reared intensively as bulls or reared extensively as steers) and (iii) to examine the effects of two slaughter weights (within production system) on these breed types and production systems. Because systems rather than discrete treatments were compared there was inevitable confounding of some production variables such as gender and feeding level or management.

Materials and Methods

Animals and management

A total of 72 spring-born male calves, 24 Holsteins (HO), 24 Friesian (FR) and

24 Charolais × Holstein-Friesians (CH), were reared from calfhood to slaughter. The HO group were the male progeny of high genetic merit (0.92 Holstein) dairy heifers imported from France and the Netherlands as part of the programme to evaluate various dairy cattle strains at the Dairy Research Centre, Moorepark (O'Connell *et al*., 2000). They were the progeny of 16 sires. The average pedigree index (RBI 95) of the heifers was 134 which compares with an average RBI 95 of 104 for Irish cows born in the same year (Buckley and Dillon, 1998). The FR animals were sourced from farms with the assistance of the South-Eastern Cattle Breeding Society (Dovea AI). These calves were the progeny of 12 bulls with less than 0.13 Holstein genes, which had been mated to cows of similar genotype. It was assumed that not more than 0.20 were from heifers. Mean birth and arrival dates at Grange Research Centre for FR and HO calves were February 3 and March 25, and February 2 and March 8, respectively. The CH calves were purchased in small numbers at a number of commercial livestock marts so as to be representative of the commercial population of CH calves. It was assumed that the CH calves were the progeny of mature Friesian cows as Charolais bulls are rarely used on dairy heifers due to the high risk of calving difficulties. The sires and birth dates were not known. Their mean arrival date at Grange was March 23.

Calf rearing was as outlined by Fallon (1992). Calves were offered 25 kg milk replacer over a 42-day feeding period, hay *ad libitum,* and up to a maximum of 2 kg/day of concentrates (800 g/kg rolled barley, 175 g/kg soyabean meal and 25 g/kg mineral/vitamin pre-mix). Calves were turned out to pasture together after a mean rearing period of 57 days and continued to receive concentrates at 1 kg per head daily for the following 4 weeks. At 3, 8 and 13 weeks after turn out, all calves were treated with Ivermectin (Ivomec, MSD Agvet) for the control of internal parasites. Calves remained together at pasture until 25 October. They were then blocked (n = 4) on live weight, within breed type and from within block were assigned to a one of four treatments represented by two production systems (intensive bull beef and extensive steer beef) × two slaughter weights (560 and 650 kg).

The animals assigned to the intensive system were immediately housed, 6 per pen, in a slatted floor shed. They were offered grass silage (dry matter (DM) 200 g/kg, crude protein (CP) 164 g/kg DM, *in vitro* DM digestibility (IVDMD) 719 g/kg, pH 3.9) *ad libitum* plus concentrates (925 g/kg rolled barley + 60 g/kg soyabean meal + 15 g/kg vitamin/mineral premix) increasing gradually from 2.5 to 6.0 kg/day over the feeding period. Concentrate levels greater than 5 kg/day were offered twice daily. Silage intake was recorded on a pen basis. They were slaughtered by pen as they reached the target mean slaughter weight.

The animals assigned to the extensive system were castrated at the time of allocation to treatment. They were then housed, primarily in individual tie-up stalls, where they remained for the duration of the winter period (156 days). For the first 55 days and final 45 days of the winter they were offered grass silage (DM 189 g/kg, CP 161 g/kg DM, IVDMD 694 g/kg, pH 4.0) *ad libitum* whereas in the intervening 56 days the silage was supplemented with 3 kg concentrates (above formulation) per head daily in two equal feeds. Following the winter period, animals were turned out to pasture for a second grazing season of 203 days. At the end of this grazing season they were housed for the second winter (161 days mean duration) and finished on grass silage (DM 168 g/kg, CP 188 g/kg DM, IVDMD 708 g/kg, pH 4.6) plus 6 kg/day of supplementary concentrates following gradual introduction. Individual silage intake was recorded for the entire duration of the first winter and for 77 days of the second winter.

Two weeks after first housing, all animals were dosed with oxfendazole (Synanthic, Pitman-Moore) to control internal parasites and they also received a dressing of deltamethrin (Butox, Hoechst Animal Health) to control external parasites. Because of an outbreak of viral pneumonia in housed cattle at Grange Research Centre during November, all animals were vaccinated for respiratory syncytial virus, infectious bovine rhinotracheitis and para-influenza 3. Shortly after housing in the second winter steers were again dosed with oxfendazole and treated with cyhalothrin (Coopers Spot-on, Schering-Plough Animal Health) to control lice.

Diet digestibility

The *in vivo* digestibility of the silage offered to the steers during the first winter was determined using twelve steers, four per breed, from corresponding blocks. Silage offered was restricted to 0.90 of the average DM intake over the previous 2 weeks, with a 7-day adaptation period prior to entry to the digestibility unit. The silage and faeces were collected and processed over five 2-day periods according to the methods of Moloney and O'Kiely (1997).

Blood measurements

All animals were blood sampled by jugular venipuncture, using a heparinised vacutainer, on five occasions over a 200-day period during the first housing period and early in the second (steers) grazing season. Blood samples were centrifuged at 2500 × g for 20 min and plasma stored at –20 ^{0}C. Plasma creatinine concentrations were determined using the Jaffe method (Randox Laboratories, Catalogue number CR 52).

Carcass measurements and dissection

After slaughter in a commercial meat plant, cold carcass weight (0.98×hot carcass weight) and weight of perinephric plus retroperitoneal fat were recorded. Carcasses were graded for conformation and fatness according to the EU Beef Carcass Classification Scheme (Commission of the European Communities, 1982). After a 24-h chilling period (4 °C), the right side of each carcass was cut along the caudal edge of the 5th rib and through the spinal column. The abdominal muscles were freed where they join the pelvic limb and the side was cut along the edge of *m. iliocostalis lumborum* through the ribs to the earlier cut at the 5th rib (Williams and Bergstrom, 1980). This divided the side into a pistola hind quarter (i.e. the hind quarter to the 5th rib without the area on the abdominal side of *m. iliocostalis lumborum*) and a fore quarter which included the afore-mentioned area. The hind quarters were then transported in a refrigerated truck to the meat laboratory and placed in a chill room (4 °C) for a further 24 h.

At ~48 h post slaughter, the pistola was divided into four joints – distal pelvic limb, proximal pelvic limb, lumbar and rib (Williams and Bergstrom, 1980). Subcutaneous fat depth and *m. longissimus* area were measured at the cut surface between the 10th and 11th ribs where the lumbar and rib joints were separated. Each joint was weighed and separated into subcutaneous fat, intermuscular fat, bone, muscle and other tissue (large blood vessels, tendons, fascia and ligamentum nuchae). The other tissue was included with bone in the statistical analyses.

Statistical analyses

Data were analysed using the general linear models procedure of the Statistical Analysis System Institute (SAS, 1996). Data on intake, digestibility, live weight and live-weight gains up to the end of the second grazing season were analysed for breed effects only. Slaughter and carcass traits were analysed as a 3 × 2 × 2 factorial with terms for block, breed, production system, slaughter weight, breed × slaughter weight, breed × production system, production system × slaughter weight, breed × slaughter weight × production system, and error. Logarithmic regressions (Berg, Andersen and Liboriussen, 1978), with a model consisting of a common regression coefficient and a separate intercept for each breed and production system, were used to relate carcass weight to slaughter weight, fore and hind quarter weights to side weight, joint and tissue weights to hind quarter weight and weights of individual tissues in the joints to total weight of these tissues in the hind quarter. The regression parameters are presented as a common regression coefficient (b) and the intercept value (a) for HO intensive system animals (bulls) and the deviations from this intercept value for FR, CH and extensive system animals (steers). The significance of the intercept differences for FR v. HO, CH v. HO, FR v. CH and extensive system animals v. intensive system animals were evaluated.

Results

Animal intake and digestibility

There was no significant difference between breeds in silage intake of the bulls either on an absolute basis or expressed relative to live weight but the CH values were numerically lower (Table 1). In contrast, in the first winter, absolute silage intake for CH steers both when offered alone, or in combination with concentrates, was significantly lower than for each of dairy breeds, which did not differ significantly. Similar results were obtained when intake was expressed relative to live weight for silage alone but when offered supplementary concentrates, FR had a higher ($P < 0.05$) relative silage intake than HO or CH, which were similar. There were no significant breed differences in silage intake during the second winter.

Apparent digestibility of grass silage DM, organic matter or crude protein was not significantly affected by breed.

Blood measurements

Mean plasma creatinine concentration was higher for CH than FR or HO at all five blood sampling times. Mean values were 85.5, 90.6 and 106.2 (s.e. 1.55) μmol/l ($P < 0.001$) for HO, FR and CH, respectively. Creatinine concentrations for animals in the intensive system were significantly higher than for those in the extensive system on the last three sampling dates. Mean values for animals in the intensive and extensive systems were 96.7 and 91.5 μmol/l ($P < 0.05$), respectively.

Animal performance, slaughter and carcass traits

Mean live weight of the calves upon arrival at Grange were 82.3, 56.6 and 73.2 (s.e. 2.3) kg ($P < 0.001$) for HO, FR and CH calves, respectively. Live weights and live-weight gains for various periods from turnout to slaughter are shown in Table 2. There were no significant effects of breed type on live weight until the end of the second grazing season when FR steers were lighter ($P < 0.05$) than HO and CH,

Table 1. Daily intake of grass silage dry matter and *in vivo* digestibility of grass silage for Holstein (HO), Friesian (FR) and Charolais × Holstein-Friesian (CH) male cattle

	Breed			s.e.	Significance
	HO	FR	CH		
	Intake of grass silage				
Bulls[1]					
Absolute (kg)	4.55	4.53	4.26	0.067	
Relative (g/kg live weight)	11.6	11.7	11.2	0.09	
Steers during first winter[2]					
Absolute - period A[3] (kg)	4.86[a]	4.74[a]	4.54[b]	0.056	**
– period B[3] (kg)	4.29[a]	4.33[a]	4.19[b]	0.037	*
Relative – period A (g/kg/live weight)	17.0[a]	17.4[a]	16.2[b]	0.22	**
– period B (g/kg live weight)	14.9[a]	15.8[b]	14.9[a]	0.22	*
Steers during second winter[2]					
Absolute (kg)	6.32	6.05	6.04	0.176	
Relative (g/kg live weight)	11.7	11.7	11.1	0.26	
	Silage digestibility				
Component[4]					
Dry matter (g/kg)	727	740	745	6.0	
Organic matter (g/kg)	744	754	762	5.4	
Crude protein (g/kg)	682	698	703	7.1	

[ab] Means without a superscript in common differ significantly ($P < 0.05$).
[1]$n = 2$ (pen) per breed
[2]$n = 12$ (animals) per breed
[3]A = silage as sole diet, B = silage + 3 kg concentrates
[4]$n = 4$ (animals) per breed

which were not significantly different. Live weight at slaughter was greater ($P < 0.05$) for CH than for FR with the value for HO being intermediate and not significantly different from either. Daily live-weight gains during the first grazing season were lower ($P < 0.05$) for FR than CH while HO animals were intermediate. There were no significant breed differences in daily gain during the first winter or second grazing season. However, differences between breeds (steers) in the second winter paralleled differences in the first grazing season with CH gaining faster ($P < 0.05$) than FR and HO intermediate. Daily live-weight gain from first turnout to slaughter tended to differ ($P < 0.08$) between breeds with higher values for CH than the dairy breeds while carcass gain per day from first turnout was significantly higher for CH than for the dairy breeds.

Slaughter weight was greater ($P < 0.05$) for extensive-system animals than intensive-system animals. Daily live-weight gain was higher ($P < 0.001$) for animals in the intensive system than on the extensive system during the first winter and from first turnout to slaughter. Similarly, carcass gain per day from first turnout was higher ($P < 0.001$) for animals in the intensive than the extensive system.

Slaughter traits and carcass measurements are shown in Table 3. Days from arrival to slaughter were similar for HO

Table 2. Live weights and live-weight gains of Holstein (HO), Friesian (FR) and Charolais × Holstein-Friesian (CH) male cattle from first turnout to slaughter

	Breed (B)				System (S)		Significance	
	HO	FR	CH	s.e.	Intensive	Extensive	B	S
Live weight (kg) at								
1st turnout	117	107	109	4.9	-	-		
End of 1st grazing season	226	210	223	6.6	-	-		
End of 1st winter	384	376	375	9.3	-	-		
End of 2nd grazing season	501^{a}	475^{b}	495^{a}	8.8	-	-	*	
Slaughter	621^{ab}	597^{a}	631^{b}	12.8	606	627	*	*
Live-weight gain (g/day) for								
1st grazing season	676^{ab}	639^{b}	702^{a}	17.9	-	-	*	
1st winter	873	886	883	21.4	1038	724		***
2nd grazing season	750	694	741	40.9	-	-		
2nd winter	815^{ab}	741^{b}	994^{a}	58.1	-	-	*	
From 1st turnout to slaughter	830	811	859	14.9	927	740		***
Carcass gain per day[1] (g)	540^{a}	533^{a}	585^{b}	7.7	622	483	***	***

[1] From 1st turnout.
[ab] Breed means without a superscript in common differ significantly ($P < 0.05$).

and CH but were slightly greater ($P < 0.01$) for FR. CH had a heavier ($P < 0.001$) carcass weight than FR or HO, which were similar. Kill-out proportion and carcass conformation score were significantly higher for CH than the dairy breeds and for FR than HO. Carcass fat score did not differ significantly for CH versus FR but was lower ($P < 0.001$) for HO. There was a system × slaughter weight interaction for fat score whereby the differences between the animals in the intensive system and the extensive system were of greater magnitude at the heavy slaughter weight. Weight of perinephric plus retroperitoneal fat was lower for CH than HO ($P < 0.05$) with FR intermediate and not significantly different. When expressed relative to carcass weight, perinephric plus retroperitoneal fat was lower ($P < 0.001$) for CH than for HO or FR which did not differ. Fat depth reflected carcass fat score numerically but the value for FR was significantly higher than HO and CH. Both *m. longissimus* area and *m. longissimus* area relative to carcass weight were similar for the two dairy strains but were significantly greater for CH.

Animals in the extensive system took significantly longer to reach slaughter than animals in the intensive system. Their slaughter weight was also greater, but because they had a lower kill-out proportion, carcass weights were similar. Fat score, weight and proportion of perinephric plus retroperitoneal fat and fat depth were all significantly greater for the extensive than the intensive system animals. The *m. longissimus* area, both absolutely and relative to carcass weight, was lower for steers than bulls. There was no significant difference between systems in carcass conformation, fore quarter or pistola weight. Days to slaughter, slaughter weight, carcass weight, carcass fat score, weight and proportion of perinephric plus retroperitoneal fat, fore quarter and pistola weight all increased significantly with

Table 3. Slaughter traits and carcass measurements of Holstein (HO), Friesian (FR) and Charolais × Holstein-Friesian (CH) male cattle

	Breed (B)				System (S)		Slaughter Weight (W)		Significance[1]		
Trait	HO	FR	CH	s.e.	Intensive	Extensive	Light	Heavy	B	S	W
Days to slaughter	665^{a}	681^{b}	666^{a}	3.3	591	750	628	714	**	***	***
Slaughter weight (kg)	621^{ab}	597^{a}	631^{b}	8.4	606	627	571	662	*	*	***
Carcass weight (kg)	326.6^{a}	321.3^{a}	353.4^{b}	4.58	332.3	335.3	309.9	357.6	***		***
Kill-out proportion (g/kg)	526^{a}	538^{b}	561^{c}	3.0	548	535	543	541	***	***	
Conformation [2]	1.51^{a}	2.18^{b}	2.96^{c}	0.085	2.25	2.18	2.17	2.26	***		
Fat score [3]	3.40^{a}	4.25^{b}	4.06^{b}	0.104	3.30	4.51	3.53	4.28	***	***	***
Perinephric + retroperitoneal fat (kg)	14.2^{a}	13.5^{ab}	12.6^{b}	0.44	12.1	14.8	11.3	15.6	*	***	***
Perinephric + retroperitoneal fat (g/kg carcass)	43.2^{a}	41.6^{a}	35.4^{b}	1.34	36.1	44.0	36.5	43.7	***	***	***
Fat depth (mm)	9.0^{a}	12.3^{b}	10.4^{a}	0.77	9.0	12.2	10.2	10.9	*	***	
M. longissimus area (mm^2)	7599^{a}	7515 ^{a}	9056^{b}	210.8	8460	7654	7986	8128	***	**	
M. longissimus area (mm^2/kg carcass)	23.3^{a}	23.6^{a}	25.8^{b}	0.55	25.8	22.9	25.6	22.9	***	***	**
Fore quarter weight (kg)	89.4^{a}	87.9^{a}	95.4^{b}	1.40	90.6	91.2	83.1	98.7	**		***
Pistola weight (kg)	74.8^{a}	73.5^{a}	81.3^{b}	1.04	75.7	77.4	72.2	80.9	***		***

^{abc} Breed means without a superscript in common differ significantly ($P < 0.05$).

[1] There was a significant S × W interaction for fat score - means were 2.76 and 3.84 for Light and Heavy groups on the Intensive system and corresponding values were 4.31 and 4.72 for the Extensive system.

[2] EU Beef Carcass Classification Scheme Scale 1 (poorest) to 5 (best).

[3] EU Beef Carcass Classification Scheme Scale 1 (leanest) to 5 (fattest).

increasing slaughter weight. In absolute terms, *m. longissimus* area was unaffected by slaughter weight but when expressed relative to carcass weight, it decreased with increasing slaughter weight. Slaughter weight had no effect on kill-out proportion, carcass conformation score, or fat depth.

Carcass and pistola composition

Pistola weight as a proportion of carcass side weight, the weights of individual pistola joints as proportions of both the side and pistola weights and the distribution of pistola weight between individual tissues are shown in Table 4. As a proportion of the side, pistola, proximal pelvic limb and loin weights did not differ between breeds but FR had a higher ($P < 0.001$) distal pelvic limb proportion than either HO or CH, which were similar. The rib proportion was lower ($P < 0.001$) for CH than HO or FR, which did not differ. As a proportion of the pistola, distal pelvic limb was significantly greater for HO than for FR or CH and for CH than for FR. Proximal pelvic limb and rib proportions were similar for HO and FR but the former was significantly greater and the latter less for CH than for either dairy breed. Loin proportion did not differ between breed types. There was no significant effect of production system on joints as proportions of the side or pistola. Increasing slaughter weight significantly reduced the proportion of pistola, and of distal and proximal pelvic limb in the side, and of distal pelvic limb in the pistola, while increasing the proportion of loin in the pistola.

There were significant differences between the breeds in the proportion of bone, muscle and fat in the pistola. The proportion of bone was highest for HO and lowest for CH, the proportion of muscle was highest for CH and lowest for FR and the proportion of total fat was highest for FR and lowest for HO. The proportions of subcutaneous and intermuscular fat followed the same trend as for total fat except that the difference between FR and CH for intermuscular fat was not significant. Animals in the extensive system had significantly lower proportions of bone and muscle and higher proportions of total fat, subcutaneous and intermuscular fat than those in the intensive system. Increasing slaughter weight significantly reduced the proportion of total bone and muscle and increased the proportions of all fat depots.

There were significant system × slaughter weight interactions for distal pelvic limb and rib joints as proportions of side and for distal and proximal pelvic limb and rib as proportions of pistola, and breed × slaughter weight interactions for total muscle and intermuscular fat as proportions of pistola. As a proportion of side weight the distal pelvic limb did not differ between the systems at the light slaughter weight but was significantly lower for animals in the intensive system than in the extensive system at the heavy slaughter weight. The rib joint as a proportion of the side weight was lower for intensive system than extensive system animals at the light slaughter weight while the opposite occurred at the heavy slaughter weight. As a proportion of pistola weight, both the distal and proximal pelvic limb joints were higher, and the rib joint proportion lower, for bulls than steers at the light slaughter weight while the opposite occurred at the heavy weight. The breed × slaughter weight interaction for total muscle as proportion of pistola weight was attributed to a lack of difference between the dairy breeds at the light slaughter weight, while at the heavy slaughter weight all breed types differed. The breed × slaughter weight interaction for intermuscular fat

Table 4. Effects of breed, production system and slaughter weight on the distribution of side weight, distribution of pistola weight and composition of pistola for Holstein (HO), Friesian (FR) and Charolais × Holstein-Friesian (CH) of male cattle

	Breed (B)				System (S)		Slaughter Weight (W)		Significance			Interaction
	HO	FR	CH	s.e	Intensive	Extensive	Light	Heavy	B	S	W	
Pistola and its components (g/kg side weight)												
Pistola	458	459	461	2.6	457	462	465	453			***	
Distal pelvic limb	55^{a}	52^{b}	54^{a}	0.6	54	54	55	53	***		***	*[1]
Proximal pelvic limb	262	263	267	2.0	263	266	268	26			**	
Loin	80	81	81	0.7	80	81	81	81				
Rib	57^{a}	59^{a}	54^{b}	0.8	56	57	56	57	**			***[2]
Components of pistola (g/kg pistola weight)												
Distal pelvic limb	121^{a}	112^{b}	118^{c}	0.9	117	117	118	116	***		*	***[3]
Proximal pelvic limb	572^{a}	574^{a}	580^{b}	2.2	575	576	576	575	*			**[4]
Loin	175	177	176	1.4	176	176	174	178			*	
Rib	123^{a}	128^{a}	118^{b}	1.8	122	124	121	125	**			***[5]
Composition of pistola (g/kg pistola weight)												
Bone	206^{a}	190^{b}	175^{c}	1.8	194	187	193	188	***	**	*	
Muscle	657^{a}	645^{b}	677^{c}	3.7	678	641	672	647	***	***	***	*[6]
Fat (total)	132^{a}	161^{b}	145^{c}	4.1	124	168	131	161	***	***	***	
Subcutaneous fat	52^{a}	70^{b}	59^{c}	2.5	51	70	53	68	***	***	***	
Intermuscular fat	81^{a}	91^{b}	85^{ab}	2.7	73	98	78	93	*	***	***	*[7]

[abc] Breed means without a superscript in common differ significantly ($P < 0.05$).
[1] S × W means were 56 v 52 and 55 v 54 for Light v Heavy for Intensive and Extensive, respectively.
[2] S × W means were 52 v 60 and 62 v 53 for Light v Heavy for Intensive and Extensive, respectively.
[3] S × W means were 121 v 114 and 116 v 118 for Light v Heavy for Intensive and Extensive, respectively.
[4] S × W means were 580 v 570 and 572 v 579 for Light v Heavy for Intensive and Extensive, respectively.
[5] S × W means were 111 v 133 and 131 v 117 for Light v Heavy for Intensive and Extensive, respectively.
[6] B × W means were 664 v 649, 665 v 625 and 686 v 668 for Light v Heavy HO, FR and CH, respectively.
[7] B × W means were 76 v 85, 77 v 104 and 81 v 90 for Light v Heavy HO, FR and CH, respectively.

proportion of the pistola was due to breed differences occurring at the heavy slaughter weight only.

Allometric regressions

The allometric regressions relating carcass weight to slaughter weight, joint weights to side weight, and joint and dissected tissue weights to pistola weight are shown in Table 5. With increasing finishing weight, the rate of carcass increase was similar to the rate of live weight increase. The breed and system intercept differences reflected the differences in kill-out proportion in Table 3. Relative to side weight, the pistola grew more slowly and the fore quarter grew more rapidly while all the joints of the pistola with the exception of the rib joint grew relatively more slowly. Relative to the pistola the distal pelvic limb grew more slowly and the rib joint grew faster, while the proximal pelvic limb and lumbar joint changed little with increasing pistola weight. Bone proportion and to a lesser extent muscle proportion declined and fat proportion, both intermuscular and subcutaneous, increased with increasing pistola weight. There were breed differences in intercepts for all pistola component weights except the lumbar joint and there were system differences in intercepts for fore quarter, total bone, total muscle, total fat, subcutaneous fat and intermuscular fat.

Discussion

The production systems, management practices and experimental measurements in the present study were designed to reflect commercial on-farm practices in Ireland and to maintain good comparability with earlier breed comparison studies at this centre (Keane *et al.,* 1989, 1990; More O'Ferrall and Keane, 1990; Keane and More O'Ferrall, 1992; Keane, 1994; Keane and Allen, 2002). The underlying principle for including CH in the present study was to put the magnitude of any differences between the dairy breeds in context. While the HO were the progeny of heifers and it is assumed that the FR were progeny of a 20:80 mix of heifers:cows, and the CH were from mature cows, this should not affect the overall post-natal performance of artificially reared calves in a calf-to-beef production system (Allen, Southgate and Cook, 1978).

Intake and digestibility

The similar silage intake across breed types for the intensive system and during the second winter in the extensive system is consistent with other reports. Southgate, Cook and Kempster (1982) and More O'Ferrall and Keane (1990) found a similar total food intake for Friesian and Charolais × Frieisan steers prior to slaughter. Southgate, Cook and Kempster (1988) reported comparable intakes between Canadian Holstein, British Friesian and Charolais × Friesian steers during the finishing period of a 16-month production system but in a 24-month production system the Canadian Holstein animals had a higher intake than the British Friesian or Charolais × Friesian animals. The latter result is also consistent with that of Keane and More O'Ferrall (1988) who found that Holstein steers had significantly higher silage intake than Friesian steers during the finishing period of a 24-month production system. Furthermore, dairy cows of higher genetic merit generally have higher forage intakes during lactation and the dry period than cows of lower genetic merit (Gordon *et al.,* 1995; O'Connell *et al.*, 2000; Buckley *et al.*, 2000a).

The absence of a breed difference in digestibility agrees with the results of Doreau and Diawara (2003) who found no

Table 5. Allometric regressions[1] ($\log_{10} Y = a + b \log_{10} X$) of carcass, joint and dissected tissue weights (*Y*) on slaughter, side and pistola weights (*X*) respectively, for Holstein (*HO*), Friesian (FR) and Charolais × Holstein-Friesian (CH) male cattle

	Regression coefficient		Intercept[2]		Intercept adjustment for			s.e.	Significance of intercept differences			
Dependent variable	*b*	s.e.	*a*	s.e.	FR	CH	Extensive systems		FR	CH	FR v CH	Extensive systems
					Slaughter weight as independent variable (X)							
Carcass weight	0.971	0.0294	–0.192	0.0820	0.009	0.028	-0.010	0.003	**	***	***	***
					Side weight as independent variable (X)							
Fore quarter weight	1.135	0.0381	–0.559	0.0843	0.002	–0.010	–0.008	0.004		*	*	*
Pistola weight	0.898	0.0286	–0.116	0.0631	–0.010	0.006	0.002	0.003			*	
Distal pelvic limb	0.810	0.0617	–0.840	0.1363	–0.032	–0.001	–0.001	0.007	***		***	
Proximal pelvic limb	0.902	0.0396	–0.368	0.0875	0.002	0.012	0.002	0.004		**	*	
Lumbar joint	0.935	0.0506	–0.955	0.1118	0.004	0.007	0.003	0.006				
Rib joint	1.062	0.1176	–1.392	0.2598	0.017	–0.020	0.008	0.011			**	
					Pistola weight as independent variable (X)							
Distal pelvic limb	0.917	0.0572	–0.511	0.0278	0.031	–0.007	–0.001	0.006	***		***	
Proximal pelvic limb	1.011	0.0263	–0.295	0.1279	0.003	0.006	–0.001	0.002		*		
Lumbar joint	1.010	0.0538	–0.808	0.2616	0.005	0.002	0.001	0.006				
Ribs joint	1.154	0.1255	–1.662	0.6108	0.018	–0.026	0.006	0.014			**	
Subcutaneous fat	1.863	0.2631	–5.575	1.2806	0.138	0.023	0.133	0.028	***		***	***
Intermuscular fat	1.923	0.2022	–5.669	0.9840	0.059	–0.011	0.126	0.022	**		**	***
Total fat	1.910	0.1925	–5.387	0.9369	0.092	0.004	0.128	0.021	***		***	***
Total muscle	0.900	0.0449	0.313	0.2185	–0.009	0.018	–0.023	0.005		***	***	***
Total bone	0.755	0.0574	0.496	0.2793	–0.039	–0.063	–0.016	0.006	***	***	***	**

[1] Units are kilograms for equations involving slaughter weight and side weight as independent variables and grams otherwise.
[2] For Holstein intensive system animals (bulls).

difference in the digestibility of hay between dry, non-pregnant Charolais and Holstein cows.

Animal performance

The superior carcass growth of the CH over the dairy breeds is in agreement with other studies (More O'Ferrall and Keane, 1990; Southgate, Cook and Kempster, 1982; Southgate *et al,* 1988). In accordance with the present findings, Southgate *et al.* (1988) and Keane and More O'Ferrall (1988) also obtained a similar growth rate between HO and FR animals.

The proportionately 0.25 greater daily live-weight gain of the animals in the intensive production system (bulls) over that of animals in the extensive production system (steers) from turnout to slaughter is consistent with previous research findings. The superiority of bulls over steers in growth rate is well documented (Fallon *et al.,* 2001), but in this instance is also attributable to differences in management and nutrition. Steen (1995) reported that bulls had proportionately 0.12–0.19 greater daily live-weight gains than steers when managed uniformly.

Carcass traits

The higher kill-out proportion of CH over FR is in agreement with the findings of More O'Ferrall and Keane (1990) and Kempster, Cook and Southgate (1988) but the higher kill-out proportion of FR over HO was not observed in other studies (Keane and More O'Ferrall, 1988; Kempster *et al.,* 1988). HO had a lower kill-out proportion than FR due largely to a higher proportion of gastrointestinal tract (Keane *et al.,* 2001). The superior conformation score of beef breeds over dairy breeds is well established (Keane, 1996). The greater conformation score of CH over FR and of FR over HO is in agreement with Kempster *et al.* (1988). The 0.78 unit poorer conformation of FR than CH was associated with a proportionately 0.17 smaller *m. longissimus* area, but there was no difference in *m. longissimus* area between HO and FR despite the 0.67 unit lower conformation score of the former. Likewise, Kempster *et al.* (1988) found that Charolais x Friesian steers had a greater *m. longissimus* area than either Friesian or Holstein which were not significantly different, despite the latter also having a poorer conformation. The poorer conformation of the HO in the present study was associated with its greater skeletal size (Keane *et al.,* 2001).

The significantly lower fat score of HO compared to both FR and CH suggests very late maturity. Southgate *et al.* (1988) compared breeds slaughtered at the same carcass fat cover and found that Canadian Holsteins required approximately an additional 65 and 45 days to reach slaughter in a 16-month and 24-month production system, respectively compared to either British Friesian or Charolais × Friesian steers. In contrast, Keane and More O'Ferrall (1988) reported no difference in slaughter weight or fat score between Friesian and Holstein steers. While carcass fat score differences between the breed types was generally reflected in fat depth differences, being lowest for HO and highest for FR, perinephric plus retroperitoneal fat was highest for HO and lowest for CH. The latter agrees with Keane and More O'Ferrall (1988) who found a numerically higher weight of perinephric plus retroperitoneal fat in Holstein compared to Friesian steers but in that study the breed differences in carcass fat score was not significant.

Differences in carcass traits between bulls in the intensive system and steers in the extensive system may have been influenced by the 20 kg difference in live weight at slaughter and in management but it is likely that they were primarily due to gender. The higher kill-out proportion and lower fat score, fat depth and perinephric plus retroperitoneal fat of the intensively-reared bulls than the extensively-reared steers is in agreement with other reports (Steen, 1995; Steen and Kilpatrick, 1995; Keane and Allen, 1998) but the lack of difference in conformation score is surprising particularly in view of the proportionately 0.11 greater *m. longissimus* area of the bulls. For similar production systems, Keane and Allen (1998) reported a 0.6 unit greater conformation score in bulls than steers for a proportionately 0.07 greater *m. longissimus* area. In the present study, the proportionate difference of 0.13 between bulls (intensive) and steers (extensive) in *m. longissimus* area scaled for carcass weight is identical to that obtained by Steen and Kilpatrick (1995) who compared bulls and steers under uniform management on a diet of *ad libitum* grass silage supplemented with concentrates. This greater *m. longissimus* area relative was reflected in a proportionately 0.15 greater conformation score.

The difference in carcass weight between the light and the heavy group was 48 kg. Unexpectedly, kill-out proportion was numerically lower for the heavy group. This contrasts with previous comparable studies where increases in kill-out proportion were recorded with heavier slaughter weights (Keane *et al.,* 1989; Keane and More O'Ferrall, 1992; Keane, 1994; Keane and Allen, 1999) although in some studies the increase was not significant (More O'Ferrall and Keane, 1990; Keane and Allen, 1998, 2002). The main reason why kill-out proportion did not increase with increasing slaughter weight is that the decreases in the proportion of hide, blood, organs and transport loss were fully offset by increases in the proportions of external and internal fat (Keane *et al.,* 2001).

While increasing slaughter weight resulted in an increase in fat score and in the weight of perinephric plus retroperitoneal fat there was no significant effect on fat depth which should follow a similar trend (Keane and Allen, 1998, 1999, 2002). In the context of this study, the literature seems to be equivocal on the effects of slaughter weight on conformation score. Some studies have shown no effect (Keane, 1994; Keane and Allen, 1998, 2002) as in the present study, while others have shown a significant improvement in conformation with increasing slaughter weight (Keane *et al*., 1989; More O'Ferrall and Keane, 1990; Keane and More O'Ferrall, 1992; Keane and Allen, 1999). However, in all those studies, with the exception of Keane and More O'Ferrall (1992), the area of the *m. longissimus* was significantly greater at the heavier slaughter weight, which contrasts with the present results. Overall, this suggests that conformation score and *m. longissimus* area are weakly correlated.

Joint and tissue proportions

The pistola, although it comprises only about 0.45 of the side weight, accounts for about two-thirds of the side value because it contains all the higher priced cuts (Keane and Allen, 1998). The absence of breed differences in the proportion of pistola in the side contrasts with previous experiments where the proportion of hindquarter was found to be greater for beef crosses compared to dairy breeds (Keane and More O'Ferrall, 1992; Keane, 1994; Keane and Allen, 2002). Keane *et al.* (1990) found no significant difference between Charolais × Friesians and Friesians in the proportions of ribs, flank, loin or pelvic limb in the side weight. This contrasts with the present results where the proportion of distal pelvic limb was higher and rib joint was lower in the CH than the FR.

The absence of an effect of the production systems on pistola or joint distribution within the side contrasts with Keane and Allen (1998) who found that intensively-reared bulls had a lower proportion of pistola in the side than extensively-reared steers. Those authors attributed this to the fact that bulls have greater development of the lower value shoulder and neck muscles. Increasing slaughter weight reduced the proportion of pistola and distal and proximal pelvic limb in the side which is consistent with previous findings (Keane and Allen, 1999, 2002) although in the latter studies the proportions of loin (Keane and Allen, 1999, 2002) and rib (Keane and Allen, 1999) also decreased, unlike the present study.

While there were significant breed differences in the joint distribution within the pistola these did not reflect the large breed differences in conformation score. There was no effect of production system on the proportions of individual joints within the pistola, which is in agreement with Keane and Allen (1998). In accord with the present findings, Keane and Allen (2002) found that increasing slaughter weight reduced the proportion of the distal pelvic limb in the pistola. However, in that study the rib proportion rather than the loin proportion increased.

The proportionately lower bone and fat and more muscle in the pistola of CH than the dairy breeds is in accord with other studies comparing beef crosses with Friesian-Holstein steers (Keane and Allen, 2002).

The proportionately greater bone and muscle and lesser fat in the intensively-reared bulls than the extensively-reared steers is consistent with other reports. Keane and Allen (1998), for production systems similar to that in the present experiment, reported that bulls had 42 g more lean and 28 g less fat per kg pistola than steers. Corresponding values for gender differences in the present experiment were 31 g and 44 g. Steen and Kilpatrick (1995) estimated that bulls had (31 g/kg carcass) more lean and less fat (40 g/kg carcass) than steers when offered a grass silage-based diet under uniform management which are in close agreement with the values for pistola in the present study.

The higher plasma creatinine concentrations in CH than in the dairy breeds and in the bulls than in steers, reflects the differences in muscle weight between the breeds and the sexes. These findings are consistent with those of Istasse *et al.* (1990) who found higher creatinine concentrations in Belgian Blue compared to Holstein bulls.

Increasing slaughter weight reduced the proportion of bone and particularly muscle and increased the proportion of fat, which concurs with previous studies (Keane and Allen, 1999, 2002).

Growth Patterns

Allometric rather than linear regressions using untransformed data were used as it has been argued that the former are more biologically appropriate for describing the part-to-whole relationships that arise in growth and carcass compositional data as well as maintaining comparability with previous studies (Keane, 1994; Keane and Allen, 2002).

As indicated by the allometric regression coefficient, the relative rate of growth of the carcass was similar to that for live weight, which concurs with the absence of a difference in kill-out proportion between the light and heavy slaughter weight groups. While this disagrees with some previous studies (e.g. Keane, 1994) it agrees with the study of Keane and Allen (2002). The breed differences in intercept values show that at any slaughter weight HO would have the lowest, FR would be intermediate and CH would have the highest kill-out proportion or carcass weight. The intercept value for production system shows that at any slaughter weight steers would have a lower carcass weight than bulls.

The lower growth rate of the pistola and the higher growth rate of fore quarter relative to the carcass side weight are in accordance with other studies using the same (Keane and Allen, 2002) or different (Keane, 1994) definitions of the quarters. Breed differences in intercept values for both pistola and fore quarter shows that at any side weight CH would have proportionately less ($P < 0.05$) forequarter than FR and HO, which were similar, and proportionately more pistola than FR ($P < 0.05$) or HO ($P = 0.07$), which again did not differ significantly. The intercept difference for production system indicates that extensively-reared steers have proportionately less forequarter than intensively-reared bulls.

The lower growth of bone and muscle and the higher growth of fat relative to the pistola is in accordance with previous studies where composition was based on the whole side (Keane *et al*., 1989, 1990; Keane and More O'Ferrall, 1992; Keane, 1994).

It is concluded that HO grew at least as fast as FR but had a lower kill-out proportion. Carcass conformation and fat scores were greater for FR than HO but muscle proportion in the pistola was lower and fat proportion was higher. Compared with FR, CH had heavier carcasses, a higher kill-out proportion and less fat and more muscle in the pistola. Compared with the intensive system (bulls), animals on the extensive system (steers) had a lower daily live-weight gain and kill-out proportion, significantly greater carcass fat measurements and a lower muscle proportion in the pistola. Increasing slaughter weight increased carcass weight, carcass fat score and the weight of perinephric plus retroperitoneal fat, and decreased the pistola as a proportion of carcass side weight and muscle as a proportion of the pistola.

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