End of project report

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Validation and Improvement of the Beef Production Sub-index in Ireland for Beef Cattle

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INTRODUCTION

In June 2007, there were 6.71 million cattle in Ireland and total disposals for that year were 1.98 million, of which 1.77 million was slaughtered and 0.21 million exported live. Total beef output was 578,000 tonnes of carcass weight equivalent in 2007 of which, 85% was exported (Bord Bia, 2008). Beef accounted for 26% of gross agricultural output in Ireland in 2007 (Department of Agriculture, Fisheries and Food, (DAFF) 2008). The source of the calf crop in Ireland is 2.29 million cows of which 49% and 51% are dairy and beef suckler cows, respectively (DAFF, 2008). The dairy herd in Ireland consists predominantly of Holstein-Friesian cows of which 52, 30 and 18% are bred to Friesian, early-maturing beef (Aberdeen Angus and Hereford) and late-maturing beef sires, respectively. The beef suckler cow herd consists mainly of crossbreds of which, 71% are late-maturing breeds and 29% are early-maturing breeds. Eighty-four percent of beef dams are bred to late-maturing sire breeds of which 40% are to Charolais, 30% to Limousin, 6% to Simmental and 4% to Belgian Blue (DAFF, 2007). Calf births in Ireland are seasonal with almost 60% of all calves born in February, March and April. There were 132,700 farms in Ireland in 2005 (DAFF, 2008) and half of these had beef production as their main enterprise. Cattle are produced predominantly on grass-based systems. The most common system is based on steer cattle (i.e. castrated males) slaughtered at 24 to 27 months of age. In a typical spring calving suckler beef herd, calves are reared on their dam for 8 months and have access to pasture during that time. Shortly after weaning they are housed for the winter and offered grass silage, which is generally supplemented with concentrates. The following spring they are let out to pasture for the summer and 3 re-housed in October/November. They are then either finished on grass silage with concentrate supplementation or in some instances let to pasture for a period prior to slaughter. Heifers are reared under similar conditions and slaughtered at approximately 20 to 24 months of age. It is estimated that some 15% of males from the suckler herd are produced as young bulls, which are generally reared indoors intensively on a high concentrate diet or an *ad libitium* concentrate diet and slaughtered at 16 to 18 months of age.
There was 523,000 tonnes of carcass weight equivalents exported in 2007. The main destination of Irish beef exports in that year was the UK which accounted for 53%, while 45% was exported to continental EU markets. International markets primarily Russia imported the remainder (Bord Bia, 2008). Because of Ireland's heavy reliance on beef exports, it is important to increase the proportion exported to the higher-priced EU markets thereby improving the profitability of the beef industry. The higher priced markets are in continental EU countries where prices are highest for carcasses of good conformation that are lean (Drennan *et al.,* 2007). Therefore it is important to produce carcasses which meet these requirements and genetic selection is of paramount importance in achieving this goal. The national cattle breeding programme responsible for genetic improvement is operated by the Irish Cattle Breeding Federation (ICBF) in conjunction with the Department of Agriculture, Fisheries and Food (DAFF), breed associations and A.I organisations.

The Irish Cattle Breeding Federation (ICBF) launched beef economically weighted genetic indices in 2005 to aid farmers in comparing animals on genetic merit for expected progeny profitability on an across breed basis. To-date, five genetic indices are published on beef sires in Ireland, each made up of traits weighted appropriately by economic weights. The five sub-indices are: *calving traits index, weaning export index, beef carcass index, milk & fertility index* and *calf value index*. However, these indices are new and their accuracy at predicting phenotypic performance and expected profitability has not been thoroughly tested. As the beef cattle produced in Ireland are reared until slaughter in different production systems, the Beef Carcass Index (BCI) was the obvious sub-index to test for validity in bull and steer production systems. The five component expected progeny differences (EPDs) which contribute to the index are weaning weight (EPDWWT), dry matter intake (EPDDMI), carcass weight (EPDCWT), carcass conformation score (EPDCONF), and carcass fat score (EPDFAT). An overall aim of this study is to examine the phenotypic performance in progeny of sires that rank either high or low in the BCI for a range of performance traits. The traits examined are not just confined to those included in the BCI but also indicator or predictor traits. Carcass meat yield and distribution are the ultimate indicators of carcass value and are therefore, imperative to genetic improvement programmes. Live animal indicators of carcass meat yield and distribution include visual muscularity and skeletal scores (Drennan *et al*., 2008). These indicators are particularly important in pedigree breeding programmes because carcass data will not be available on those animals. Accuracy of selection can be enhanced by using predictor traits, which are genetically correlated with the goal trait. For example, linear muscularity and skeletal scoring (visual assessment) are envisaged to form an integral part of early carcass merit prediction in the BCI (Evans *et al.,* 2007). Consequently, the correlated responses to selection on the BCI for live animal measurements and carcass composition needs to be investigated.

Although breeds for beef production were evaluated in the past (Southgate *et al.,* 1982; Kempster *et al.,* 1982; Keane, 1994; Hardy and Fisher, 1996) it is reasonable to assume that given recent genetic improvement in beef breeds and particularly in dairy breeds, there is a need to re-examine the differences between breeds across primary input and output traits. Furthermore, many contemporary breed comparison studies were confined to progeny from the dairy herd (Keane, 1994; McGee et al., 2005, 2007; Kirkland et al., 2007; Keane and Drennan, 2008). The minority of studies comparing sire breeds from non-dairy dams have generally not quantified important traits for the beef producer, such as, animal intake or carcass composition and value. Accordingly, there is a deficit in the literature in this regard.

Therefore, the objectives of the following study were to:

a. Quantify the effect of sire genetic merit for BCI on:
    1. feed intake, growth and carcass traits of progeny managed under bull or steer beef production systems.
    2. live animal scores, carcass composition and plasma hormone and metabolite concentrations in their progeny.

b. Compare the progeny of :
    1. Late-maturing beef with dairy breeds and
    2. Charolais (CH), Limousin (LM), Simmental (SM) and Belgian Blue (BB) sires bred to beef suckler dams,

    for feed intake, blood hormones and metabolites, live animal measurements, carcass traits and carcass value in bull and steer production systems.

EXPERIMENT 1: Intake, growth and carcass traits in male progeny of sires differing in genetic merit for beef production

Introduction

Economically weighted genetic selection indices for Irish beef sires were first published by the Irish Cattle Breeding Federation (**ICBF**) in 2005 (Evans *et al.*, 2007) to aid producers in identification of superior sires based on the expected profitability of their progeny. These indices are comprised of economically weighted traits. For example, the beef carcass index (**BCI**) estimates the genetic potential of a sire to generate profitable progeny for slaughter. Genetic evaluations in Ireland utilise purebred and crossbred data and expected progeny differences (**EPD**) are expressed on an across breed basis. Although economic indices are currently being used in Ireland, their efficacy has not yet been validated through research under a controlled environment or under different beef cattle production systems.

Keane and Diskin (2007) reported that progeny of sires with high genetic merit for carcass growth had a greater kill-out proportion and carcass weight than the progeny of sires of low genetic merit for carcass growth. In agreement, Crews (2002) reported differences among purebred progeny sired by Charolais bulls differing in EPD to be at or near the theoretical expectations for hot carcass weight, fat thickness, muscle area, percent lean yield and marbling score. Similarly, Williams *et al.* (2004) reported positive associations between Charolais sire genetic merit, estimated from seedstock herds, and crossbred progeny performance in 31 commercial herds. However, the regression coefficients of weaning weight on sire EPD for weaning weight were significantly lower (0.66) than expected, which those authors suggested may have been due to a genotype by environment interaction between seedstock and commercial herds (Williams *et al.*, 2004). A similar observation was recorded by Núñez-Dominguez *et al.* (1993) with lower than expected responses to sire genetic merit for weaning weight in F_1 crossbred progeny. However, there is a deficit of information published pertaining to economically weighted genetic selection indices, particularly on an across breed basis.

The objective of this study, therefore, was to quantify the effect of sire genetic merit for BCI on feed intake, growth and carcass traits of progeny managed under bull or steer beef production systems. The phenotypic traits investigated in the present study include all of those actually included in the BCI. Analysis on the effect of BCI on live animal muscular and skeletal scores, scanned muscle and fat depth, carcass composition and carcass value (based on commercial value of meat cuts obtained in carcass dissection work) is discussed elsewhere (Clarke *et al.*, 2008).

Material and methods

Study design

Male progeny from 22 late-maturing beef breed sires selected as either high (n=11) or low (n=11) for the Irish genetic index, BCI, were purchased between October 2005 and January 2006. The BCI of a sire is the linear sum of the product between the economic weight and EPD for five individual traits and thus, is related to the expected profitability of the progeny at slaughter. Traits (relative emphasis and direction of economic weight included in parenthesis) included in the current BCI (2008) were weaning weight (+0.24), dry matter (**DM**) intake (-0.12), carcass weight (+0.46), carcass conformation score (+0.11) and carcass fat score (-0.07). The relative emphasis for each trait is calculated as the product of the economic value and the genetic standard deviation for the trait as a proportion of the other traits in the index. Within both the high and low genetic merit groups there were 5 Charolais, 3 Limousin, 2 Simmental and 1 Belgian Blue sires (Table 1). Details of the BCI values for each sire and the EPD for weaning weight (EPD_{WWT}), DM intake (EPD_{DMI}), carcass weight (EPD_{CWT}), conformation score (EPD_{CONF}), and fat score (EPD_{FAT}) are summarised in Table 1. The values used are from the ICBF February 2008 genetic evaluation run. Expected progeny differences are expressed in their units of measure with weaning weight, daily DM intake and carcass weight measured in kg, and both carcass conformation and fat score measured separately on a scale of 1 (poor conformation and low fat cover) to 15 (good conformation and high fat cover) as described by Hickey *et al.* (2007). Overall, progeny of the high compared with low BCI sires selected were expected to be €42 more profitable. On an individual trait basis, on average, the differences between the high and low BCI sires were 5.9 kg in sire EPD_{WWT}, 0.02 kg in sire EPD_{DMI}, 13.0 kg in sire $EPD_{CWT,}$ 0.24 in sire EPD_{CONF} and 0.44 in sire EPD_{FAT}. The reliabilities for all sires were based on their progeny reared in Irish herds and slaughtered in Ireland. Reliability values for BCI ranged from 91% to 99% with a mean value of 96% and reliability of sire EPD for the individual traits ranged from 78% to 99% with a mean value of 93%.

The progeny originated from 28 commercial suckler beef herds from which, the number of purchased progeny per herd varied from 1 to 10. Animals were primarily born in spring to a multiparous dam and reared on their dam at pasture until weaning at approximately 9 months of age. For the purpose of the analysis in the present study, breed of dam was separated into 4 groups: 1) Limousin and Limousin cross; 2) Simmental and Simmental cross; 3) Aberdeen Angus and Hereford with their associated crosses; and 4) Belgian Blue and Charolais with their associated crosses.

The purchased weanlings were assembled at the Grange Beef Research Centre, where they remained for the duration of the study until slaughter. Paternal verification of each animal purchased was determined using 11 DNA-markers including the 9 microsatellite markers recommended by the International Society of Animal Genetics (2008) and only animals with a positive paternal test outcome were retained. A total of 107 animals were included in the study. Number of progeny per sire varied from 1 to 10 with a mean number of 5.

Animal management

Upon arrival at the research centre, all animals were vaccinated as a prophylactic measure against respiratory disease and treated for the control of ecto- and endo-parasites. Animals were offered grass silage *ad libitum* and 2 kg of supplementary concentrates during the pre-experimental period. While trying to maintain an equal number of progeny per sire, each animal was randomly allocated to one of two production systems; either an "intensive" bull production system with slaughter age at about 16 months of age or an "extensive" steer production system with slaughter at about 24 months of age. As some animals were already castrated on arrival, castration of the remaining animals destined for the steer production system took place at this time. A total of 50 bulls and 57 steers were used in the study.

Bulls were housed in groups of 7 animals in slatted floor pens and offered feed individually using electrically controlled Calan-Broadbent gates. The concentrate allowance was increased gradually until available *ad libitum* (at 1.10 times each animals daily intake), while concurrently, the grass silage allowance was reduced to 1 kg of DM per head daily. Refused concentrate and silage feed was discarded once weekly and 3 times weekly, respectively. The bulls remained on this high concentrate diet for 133 days from 13 February until slaughter on 26 June 2006. The concentrate offered contained 865 kg barley, 70 kg soya bean meal, 50 kg molasses and 15 kg minerals and vitamins per tonne.

Steers were offered grass silage *ad libitum* plus 2 kg of concentrates (same formulation as above) per head per day until 13 March 2006 after which, the daily concentrate offered was decreased to 1 kg per head and subsequently discontinued from 3 April 2006. At the end of the winter housing period, steers were turned out to pasture on 18 April where they grazed a predominantly perennial ryegrass (*Lolium perenne*) based sward in 2 batches under a rotational grazing, paddock-based system. Each grazing batch was balanced for genetic merit and as far as possible, for sire. On 18 October 2006 the steers were re-housed in slatted floored pens with 7 animals per pen and offered grass silage *ad libitum* plus a mineral vitamin supplement through individual electrically controlled Calan-Broadbent gates until 22 December 2006 (59 days). Concentrates (same formulation as above) were then introduced to the diet and the allowance was increased gradually until available *ad libitium* in addition to 1 kg of grass silage DM per head daily from January 2007 until slaughter on 13 or 27 April 2007 (mean 87 days). The steers were slaughtered in two groups for logistical reasons and were balanced for genetic merit and as far as possible for sire on each slaughter date. Slaughter was carried out in the same commercial meat plant.

Animal measurements

Animals were weighed using calibrated scales on 5 January 2006 having received a standard diet from the time of arrival at the research centre. This weight is referred to as weaning weight. Bulls were subsequently weighed at 28 d intervals from then until slaughter resulting in a total number of 7 weight records per bull. Steers were also weighed at 28 d intervals from the initial weight to housing in October 2006 after which, they were weighed every 14 d until slaughter in April 2007 resulting in a total number of 27 weight records per steer. Weighing always occurred prior to the morning feeding or when at pasture, prior to movement to the next paddock in the rotation. Live weight gain was calculated by fitting a linear regression through live weights during each of the feeding periods (grazing period, silage period and finishing period) for each animal separately. For each period, metabolic weight (**MWT**) was calculated as average live weight$^{0.75}$ for the interval in question. Individual daily herbage DM intake was estimated for the steers over a 6 day period in late July and early August, using the n-alkane technique (Mayes *et al.*, 1986) by means of a "controlled release capsule" (Captec (NZ) Ltd., Auckland, New Zealand). Dosing, sampling and processing methodology used was as described by Butler *et al.* (2003) with the exception that faecal grab sampling were carried out once daily and all samples were freeze dried. During the intake recording period each grazing batch was moved to a new paddock every second day.

Post-slaughter, hot carcass weight was recorded and cold carcass weight was taken as 0.98 of hot carcass weight. Kill-out proportion was cold carcass weight expressed as a proportion of final live weight prior to slaughter. Carcass conformation and fat scores were recorded mechanically (Allen and Finnerty, 2000) according to the EU beef carcass classification scheme (Commission of the European Communities, 1982) on a continuous 15 point scale. Live weight and carcass gain per day of age was calculated by dividing live weight at slaughter and cold carcass weight, respectively, by age in days of each animal at slaughter. Estimated carcass gain (g/day) during the period in which animals were finished on *ad libitum* concentrates was obtained by multiplying average daily live weight gain (g/d) during this period by kill-out proportion (g/kg) at slaughter.

Feed processing and laboratory analysis was as described by Owens *et al.* (2008). Estimated net energy (**NE**) content of the various diets was based on the chemical composition and *in vitro* dry matter digestibility (Table 2) according to O'Mara (1996). Feed efficiency was calculated by dividing live weight gain into NE intake (expressed as UFV). Residual feed intake, defined as the difference between an animal's actual feed intake and that predicted on the basis of

requirements for maintenance of live weight and average daily gain (Crews, 2005), with negative or lower values more desirable, was calculated. Residual feed intake was assumed to be represented by the residuals from a regression of average daily NE intake on metabolic weight and live-weight gain.
Using the five individual traits of the BCI, the observed phenotypic profit measure (€) was calculated for each individual animal using the following series of steps. The phenotypic performance for all five BCI traits of one random animal from the experiment were taken and all animals were then expressed relative to the performance of this animal by subtraction of the chosen animal's performance from all the trial animals. These new relative performances for each trait were then multiplied by the economic value for the trait as used in the BCI and summed to yield the actual relative profit (€). Thus, the chosen animal's performance became the basis of comparison with a zero for all traits. The economic values used in this calculation were the same as those used in the February 2008 release of proofs for the calculation of the BCI. These were €1.04 per kg increase in weaning weight, -€21.94 per kg increase in DM intake consumed, €2.34 per kg increase in cold carcass weight, €10.74 per unit increase in carcass conformation score (scale of 1-15) and -€6.08 per kg increase in carcass fat score (scale of 1-15). The observed difference in value for the progeny of the high and low BCI sires, for each of the five component traits was then expressed as a proportion of the total difference in value. The same analysis was carried out on the sire EPD (as in Table 1) with the expected difference in value between the high and low EPDs for each of the five component traits also was expressed as a proportion of the total difference in value.

Statistical analysis
The association between genetic merit for BCI, production system and the aforementioned variables was determined using a fixed effect linear model in PROC GLM (SAS, 2008). Both genetic merit and production system were treated as class variables. Confounding variables adjusted for in the statistical model, where significant ($P<0.05$), were sire breed, dam breed, dam parity and age at the time of measurement centered within production system. Age centered within production system was treated as a continuous variable. Non-linear associations between age and the dependent variables as well as the existence of an interaction between genetic merit and production system were also tested for significance in the model. Significance of individual terms in the model was based on the F-test with the appropriate degrees of freedom. In the analysis of variables recorded during the grazing and pre-finishing silage periods, only steers were included in the data set and thus production system was omitted from the model. Grazing batch was included in the model of analysis for data relating to the grazing period. Data pertaining to the finishing periods for both bulls and steers were analyzed together.
An additional series of analyses included the independent variable, genetic merit of the sire, as a continuous variable, whereby genetic merit was defined as sire BCI, EPD_{WWT}, EPD_{DMI}, EPD_{CWT}, EPD_{CONF}, and EPD_{FAT}. All analyses were undertaken using fixed effect linear models in PROC GLM (SAS, 2008). Non-linear associations between genetic merit and the dependent variable and interactions between genetic merit and production system were also investigated. Sire breed was not included in this analyses as genetic evaluations in Ireland are evaluated and presented across breeds.
For steers only, the correlation between DM intake during the grazing period, grass silage intake period and *ad libitium* concentrate finishing period was estimated. Furthermore, the association between EPD_{DMI} and steer progeny DM intake in the present study was evaluated for steers across the three feed intake periods in a separate analysis to determine if the association between sire EPD_{DMI} and steer progeny DMI differed between different diets. The difference between the 'expected profit' and 'observed profit' between the high and low progeny was determined using PROC GLM (SAS, 2008). The existence of an interaction between genotype (high and low sires) and measure of value (expected profit and observed profit) was used to determine if the difference between the profit measures differed between genotypes. In a separate analysis observed profit in the progeny was regressed on sire BCI in an interaction with sire genotype to test whether the slope differed between the different genotypes.

Results

Feed intake
The effect of BCI, when treated as a class variable on feed intake measures in the steers during the grazing and silage periods is summarised in Table 3. There was no significant difference between the steer progeny of high and low BCI sires for intake, mean live weight, live weight gain or metabolic weight during the grazing and silage periods. Net energy intake expressed relative to live weight during the grazing period tended to be significantly lower, while DM and NE intake expressed relative to live weight during the silage period were lower ($P<0.05$) in the steer progeny of the high compared with the low BCI sires.
The effects of BCI, when treated as a class variable and production system (bulls and steers) on feed intake and efficiency measures during the concentrate finishing period are summarised in Table 4. There was no significant interaction between BCI and production system for any of the traits analysed. There was no significant difference in intake between the genetic groups, although the progeny of the high BCI sires were heavier ($P=0.051$) than the progeny of the low BCI sires. No significant difference was evident in live weight gain or carcass gain, intake expressed relative to live weight, feed efficiency or RFI between the two genetic groups.

Bulls had lower (P<0.001) intake, mean live weight and metabolic weight than steers during the finishing period. Intake expressed relative to live weight and metabolic weight were greater (P<0.001) in bulls. Greater (P<0.001) live weight gain, carcass weight gain and feed efficiency was found in bulls than steers. There was no significant difference in RFI between bulls and steers during the finishing periods.

The effect of a €100 increase in sire BCI and a unit increase in sire EPD_{WWT}, EPD_{DMI}, EPD_{CWT}, EPD_{CONF} and EPD_{FAT} on progeny DM intake, live weight, live weight gain and efficiency measures during the concentrate finishing period are summarised in Table 5. There was no evidence of non-linear effects between the genetic merit traits and the different performance measures however, the linear associations sometimes differed with production system.

Mean live weight and metabolic weight during the finishing periods increased (P<0.05) with increasing sire BCI and sire $EPD_{WWT.}$ There was no significant effect of BCI or EPD_{WWT} on intake, live weight gain, carcass gain, feed efficiency, intake expressed relative to live weight or RFI.

Feed intake during the finishing period increased (P<0.001) by 1.10 (SE=0.32) kg per day with increasing sire EPD_{DMI} and was consistent across both production systems. The effect of EPD_{DMI} on mean live weight and metabolic weight differed with production system with both increasing (P<0.001) with increasing sire EPD_{DMI} in bulls but with no significant effect in steers. There was no other statistically significant effect of sire $EPD_{DMI.}$

Mean live weight and metabolic weight increased (P<0.001) with increasing $EPD_{CWT.}$ There were no other significant associations with sire $EPD_{CWT.}$ Sire EPD_{CONF} and sire EPD_{FAT} were not significantly associated with feed intake or feed efficiency measures.

Within the steers, the correlation between DM intake during the grazing period and silage and *ad libitium* concentrate feeding periods was 0.30 and 0.26, respectively, which were both different (P<0.05) from zero. A higher correlation of 0.53 was obtained between DM intake in the silage and concentrate feeding periods, which was different (P<0.001) from zero. The linear regression coefficient of sire EPD_{DMI} on steer DM intake was 0.02 (SE=0.587), 1.04 (SE=0.382), and 1.11 (SE=0.323), when offered grazed grass, silage and concentrates, respectively.

Growth and carcass traits

Progeny of high BCI sires had a 14 kg heavier carcass (P<0.05) and 24 g higher carcass gain per day of age (P<0.05) than the progeny of the low BCI sires (Table 6). There were no significant differences between the two genetic groups for kill-out proportions and carcass conformation score, but progeny of the high BCI sires had a lower (P<0.05) carcass fat score. There was no significant difference in weaning weight between the two production systems. Bulls were lighter (P<0.001) at slaughter, had a higher carcass conformation score, kill-out proportion, live weight gain per day of age and carcass gain per day of age (P<0.001) and a lower carcass fat score (P<0.001) than steers.

The effect of a €100 increase in sire BCI and a unit increase in sire EPD_{WWT}, EPD_{DMI}, EPD_{CWT}, EPD_{CONF} and EPD_{FAT} and growth and carcass related traits are detailed in Table 7. Non-linear associations were not evident although the associations sometimes differed according to production system. Slaughter weight, carcass weight, live weight gain per day of age and carcass gain per day of age increased (P<0.05), whereas carcass fat score decreased (P<0.001) with increasing BCI. The effect of BCI on kill-out proportion differed with production system with no significant effect in bulls and a positive (P<0.01) effect in steers. There was no significant effect of BCI on weaning weight or carcass conformation score.

Weaning weight, live weight at slaughter and carcass weight, and live weight gain per day of age increased (P<0.05) with increasing sire $EPD_{WWT.}$ Sire EPD_{WWT} was not associated with carcass fat score in bull progeny but was negatively associated (P<0.01) with carcass fat score in steers. There were no other significant effects of sire EPD_{WWT} on carcass traits. Weaning weight increased (P<0.05) and kill-out proportion decreased (P<0.01) with increasing sire $EPD_{DMI.}$ The effect of sire EPD_{DMI} on slaughter weight, carcass weight, live weight gain per day of age and carcass gain per day of age was positive (P<0.01) in the bulls with no significant effect (P<0.05) in the steers.

Carcass weight increased by 1.3 kg (SE=0.31) per kg increase in sire EPD_{CWT}. Additionally slaughter weight, live weight gain per day of age also increased (P<0.01), whereas carcass fat score decreased (P<0.01) with increasing sire EPD_{CWT}. There was no significant effect of increasing sire EPD_{CWT} on carcass conformation score in the progeny. Carcass conformation score increased by 0.94 (SE=0.318) per unit increase in sire $EPD_{CONF.}$ Kill-out proportion increased (P<0.001), whereas carcass fat score decreased, (P<0.05) with increasing sire $EPD_{CONF.}$ There were no other significant effects of sire $EPD_{CONF.}$ Carcass fat score increased by 1.04 (SE=0.249) per unit increase in sire EPD_{FAT}. Increasing sire EPD_{FAT} had no significant effect on carcass weight in bulls and a negative effect (P<0.05) in steers. Carcass conformation score decreased (P<0.05) with increasing sire EPD_{FAT}. There were no other significant effects of sire $EPD_{FAT.}$

Conclusions

Sire EPD values for weaning weight, DM intake, carcass weight and carcass conformation and fat scores were shown to be an accurate reflection of progeny performance. Furthermore, the regression of sire EPD_{DMI}, estimated from data from a performance test station where animals are fed an *ad-libitium* high concentrate diet as well as from correlated traits, on steer DM intake did not differ when the animals were fed contrasting diets. Additionally, the observed

differences in profitability of progeny of sires differing in BCI show good agreement with the expected profitability values. Results from this study indicate that the BCI is a useful tool in the selection of genetically superior sires and that actual progeny performance under the conditions of this study is within expectations for both bull and steer beef production systems.

Table 1. Values for the beef carcass index (BCI), expected progeny differences for weaning weight (EPD_{WWT}), dry matter intake (EPD_{DMI}), carcass weight (EPD_{CWT}), carcass conformation score (EPD_{CONF}) and carcass fat score (EPD_{FAT}) for sires of high and low BCI used in the study

Sire	Breed	BCI (€100)	EPD_{WWT} (kg)	EPD_{DMI} (kg)	EPD_{CWT} (kg)	EPD_{CONF} (score) [a]	EPD_{FAT} (score) [b]
High BCI sires							
VDC	BB	142	9.79	-0.43	36.92	2.52	-1.44
CF52	CH	162	20.72	-0.05	46.94	2.04	-1.33
HWN	CH	150	14.65	0.02	45.11	2.14	-1.15
HKI	CH	146	8.65	-0.04	45.84	2.05	-1.07
MDO	CH	140	19.91	0.29	41.99	2.09	-0.84
NXB	CH	124	12.24	0.24	40.69	1.68	-0.52
ROX	LM	122	6.64	-0.20	34.33	2.46	-0.73
ORO	LM	89	6.52	-0.26	22.05	1.91	-0.66
NIN	LM	79	0.24	-0.17	22.02	2.00	-0.39
HKG	SI	107	11.29	0.26	34.70	1.55	-0.56
MLM	SI	89	17.79	0.60	28.10	1.59	-0.20
Weighted Mean		129	12.54	0.04	38.50	2.00	-0.84
Low BCI sires							
NRO	BB	93	-1.89	-0.42	21.56	2.70	-1.01
NWK	CH	122	21.48	0.46	38.03	1.70	-0.49
CF57	CH	114	17.49	0.21	33.89	1.62	-0.67
NBC	CH	96	6.93	-0.45	22.14	1.77	-1.31
CF43	CH	95	1.88	0.31	33.98	1.99	0.12
KFC	CH	92	6.39	0.47	32.19	1.83	-0.16
DGA	LM	53	-9.44	-0.36	14.34	1.99	-0.02
PTS	LM	46	-5.78	-0.62	7.45	1.66	-0.45
LUR	LM	45	-3.33	-0.22	10.69	1.75	0.02
BDJ	SI	66	15.48	0.44	20.04	1.26	0.09
HRG	SI	61	7.82	0.29	18.08	1.31	-0.50
Weighted Mean		87	6.66	0.06	25.55	1.76	-0.40

[a]EU Beef Carcass Classification Scheme Scale 1 (poorest) to 15 (best)
[b]EU Beef Classification Scheme Scale 1 (leanest) to 15 (fattest)

Table 2: Chemical composition and *in vitro* dry matter digestibility of concentrates, grass silage and fresh grass (s.e)

	System					
	Bulls		Steers			
	Concentrates	Silage[a]	Grass	Silage[b]	Concentrates	Silage[c]
Dry matter (g/kg)	819 (14.2)	242 (65.3)	162 (11.3)	249 (23.9)	799 (17.8)	244 (22.4)
Crude protein (g/kg DM)	124 (10.2)	143 (9.1)	194 (33.9)	144 (6.7)	117 (10.4)	143 (16.4)
Ash (g/kg DM)	38 (5.8)	80 (12.1)	-	72 (7.2)	37 (5.3)	93 (11.7)
Neutral detergent fibre (g/kg DM)	153 (33)	588 (38.9)	-	538 (32.1)	157 (32.9)	538 (32.1)
Acid detergent fibre (g/kg DM)	46 (4.9)	-	-	-	57 (24.7)	-
In vitro dry matter digestibility (g/kg DM)	869 (34.8)	674 (53)	735 (37.9)	745 (21.3)	855 (20.8)	727 (26.8)
pH	-	3.9 (0.54)	-	3.7 (0.08)	-	3.9 (0.31)
Ammonia (mg/100ml)	-	83 (18.1)	-	69 (23.3)	-	80 (26.2)

[a]Silage offered with concentrate to bulls at a rate of 1 kg DM per head daily
[b]Silage offered to steers *ad libitum*
[c]Silage offered with concentrates to steers at a rate of 1 kg DM per head daily

Table 3. Effect of sire beef carcass index € (BCI) on dry matter (DM) intake and net energy (NE) during the grazing and silage periods in steer progeny

	Grazing Period[a]				Silage Period[b]			
	High	Low	s.e.d.	Significance[c]	High	Low	s.e.d.	Significance[c]
DM intake (kg/day)	7.8	8.1	0.35	ns	7.8	8.0	0.24	ns
NE intake (UFV/day)[d]	7.2	7.5	0.32	ns	6.6	6.7	0.20	ns
Live weight (kg)[e]	527	505	15.7	ns	581	564	14.0	ns
Metabolic weight (kg)[e]	109	107	1.9	ns	118	116	2.2	ns
DM intake (g/kg live weight)	15.0	16.1	0.65	ns	13.4	14.2	0.30	*
NE intake (UFV*1000/kg live weight)	13.7	14.9	0.26	P=0.054	11.3	11.9	0.26	*
Live weight gain (g/day)	852	832	37.0	ns	467	386	66.3	ns

[a]Grazing period refers to the period from turnout on 18 April 2006 until housing on 18 October 2006
[b]Silage period refers to from housing on 18 October 2006 until 22 December 2006
[c]Significance levels: *P<0.05; ns = P>0.05
[d]UFV = Unite Fourragere Viande – Feed unit for meat production
[e]Mean live or metabolic weight during each period

Table 4. Effect of sire beef carcass index € (BCI) and production system on dry matter (DM) intake, net energy (NE) intake, feed efficiency (live weight gain/net energy intake) and residual feed intake during the finishing period

	BCI			Production System (PS)			Significance[a,b]	
	High	Low	s.e.d.	Bulls[c]	Steers[d]	s.e.d.	BCI	PS
DM intake (kg/day)	10.3	10.2	0.23	9.5	11.0	0.23	ns	***
NE intake (UFV/day)[e]	11.3	11.1	0.26	10.4	12.1	0.26	ns	***
Live weight (kg)[f]	612	590	12.0	511	691	12.0	*P*=0.051	***
Metabolic Wt (kg)[f]	123	119	1.8	107	135	1.8	*P*=0.056	***
DM intake (g/kg live weight)	17.1	17.3	0.25	18.5	15.9	0.25	ns	***
NE intake (UFV*1000/kg live weight)	18.7	19.0	0.28	20.3	17.4	0.28	ns	***
Live weight gain (g/day)	1276	1292	56.6	1588	980	56.6	ns	***
Carcass gain (g/day)	749	736	32.7	935	550	32.4	ns	***
Feed efficiency (g of live weight gain per UFV intake)	0.12	0.12	0.004	0.16	0.08	0.004	ns	***
Residual feed intake (UFV/day)	-0.02	0.10	0.144	0.06	0.47	0.144	ns	ns

[a]Significance levels: ***$P<0.001$; ns = $P>0.05$

[b]There was no significant BCI × PS interactions

[c]Bulls offered a diet based on ad libitium concentrates during the finishing period (133 days)

[d]Steers offered a diet based on ad libitium concentrates during the finishing period (mean 87 days)

[e]UFV = Unite Fourragere Viande – Feed unit for meat production

[f]Mean live or metabolic weight during each period

Table 5. Regression co-efficients (s.e) for beef carcass index (BCI), expected progeny differences for weaning weight (EPD_{WWT}), dry matter intake (EPD_{DMI}), carcass weight (EPD_{CWT}), conformation (EPD_{CONF}) and fat (EPD_{FAT}) score on feed intake, efficiency (live weight gain/net energy intake) and residual feed intake during the finishing period[a]

	BCI (/€100)	EPD_{WWT} (kg)	EPD_{DMI} (kg)	EPD_{CWT} (kg)	EPD_{CONF} (score) [b]	EPD_{FAT} (score) [c]
DM intake (kg/day)	0.17 (0.329)	0.02 (0.013)	1.10 (0.32)***	0.02 (0.011)	-0.53 (0.307)	0.21 (0.214)
NE intake (UFV/day)[d]	0.18 (0.37)	0.02 (0.014)	1.2 (0.36)***	0.017 (0.0119)	-0.6 (0.35)	0.3 (0.24)
Live weight (kg)[e]	39.1 (17.33)*	1.8 (0.67)**	92.3 (22.68)*** 25.5 (25.47)	1.9 (0.54)***	-11.7 (16.72)	2.3 (11.59)
Metabolic weight (kg) [e]	5.9 (2.61)*	0.28 (0.101)**	14.3 (3.4)*** 3.9 (3.82)	0.3 (0.08)***	-1.8 (2.52)	0.4 (1.75)
DM intake (g/kg live weight)	-0.6 (0.37)	-0.006 (0.0148)	-0.004 (0.3808)	-0.019 (0.0119)	-0.498 (0.3435)	0.13 (0.2421)
NE intake (UFV*1000/kg live weight)	-0.6 (0.41)	-0.008 (0.0166)	0.034 (0.4255)	-0.021 (0.0133)	-0.557 (0.3839)	0.172 (0.2705)
Live weight gain (g/day)	37.9 (84.24)	1.7 (3.32)	65 (87.1)	1.9 (2.67)	-43 (79.3)	-17 (56.1)
Carcass gain (g/day)	53 (48.81)	1.3 (1.94)	19 (51)	2 (1.57)	9 (45.5)	-26 (32.4)
Feed efficiency (g of live weight gain per UFV*1000 intake)	5.2 (6.69)	-0.004 (0.2633)	-10 (7)	0.1 (0.22)	6 (6.3)	-6 (4.4)
Residual feed intake (UFV/day) [d]	-0.4 (0.209)	-0.01 (0.008)	0.25 (0.215)	-0.01 (0.007)	-0.31 (0.2)	0.25 (0.136)

[a]Where the associations differed significantly by system, the solutions are both presented as bulls and steers, from left to right
[b]EU Beef Carcass Classification Scheme Scale 1 (poorest) to 15 (best)
[c]EU Beef Classification Scheme Scale 1 (leanest) to 15 (fattest)
[d]UFV = Unite Fourragere Viande – Feed unit for meat production
[e]Mean live or metabolic weight during each period

Table 6. Effect of sire beef carcass index (BCI) and production system on growth and carcass traits

Trait	BCI			Production System (PS)			Significance[a, b]	
	High	Low	s.e.d.	Bulls	Steers	s.e.d.	BCI	PS
Weaning weight (kg)	374	357	9.1	364	367	9.1	ns	ns
Slaughter weight (kg)	681	662	13.0	619	724	13.0	ns	***
Carcass weight (kg)	390	376	6.67	353	413	6.67	*	***
Kill-out proportion (g/kg)	581	575	4.3	587	568	4.3	ns	***
Conformation score[c]	10.4	10.3	0.25	11.0	9.7	0.25	ns	***
Fat score[d]	8.4	9.0	0.28	7.9	9.5	0.29	*	***
Live weight gain/day of age (g)	1120	1094	23.3	1307	908	23.4	ns	***
Carcass gain/day of age (g)	648	624	13.0	754	518	13.1	*	***

[a]Significance levels: ***P<0.001; *P<0.05; ns = P>0.05
[b]There was no significant BCI × PS interactions
[c]EU Beef Carcass Classification Scheme scale 1 (poorest) to 15 (best)
[d]EU Beef Classification Scheme scale 1 (leanest) to 15 (fattest)

Table 7. Regression co-efficients (s.e) for beef carcass index (BCI), expected progeny differences for weaning weight (EPD_{WWT}), dry matter intake (EPD_{DMI}), carcass weight (EPD_{CWT}), and carcass conformation (EPD_{CONF}) and fat (EPD_{FAT}) score on growth and carcass traits[a]

	BCI (/€100)	EPD_{WWT} (kg)	EPD_{DMI} (kg)	EPD_{CWT} (kg)	EPD_{CONF} (score)[b]	EPD_{FAT} (score)[c]
Weaning weight (kg)	18.5 (13.5)	1.0 (0.53)*	35.4 (13.88)*	0.8 (0.43)*	0.6 (12.78)	3.1 (9.12)
Slaughter weight (kg)	39.2 (18.59)*	1.8 (0.72)*	93.5 (24.51)*** 21.1 (27.52)	1.9 (0.59)**	-14.8 (17.87)	1.2 (12.39)
Carcass weight (kg)	30.9 (9.83)**	0.8 (0.40)*	40.7 (13.66)** -4.9 (15.33)	1.3 (0.31)***	11 (9.66)	9 (9.45) -19 (9.22)*
Kill-out proportion (g/kg)	-1.3 (8.37) 24.7 (8.94)**	-0.4 (0.25)	-19.2 (6.21)**	-0.2 (0.26) 0.8 (0.29)***	28.5 (5.38)***	-7.6 (4.1)
Conformation score[b]	0.68 (0.342)	0.01 (0.014)	-0.49 (0.351)	0.02 (0.011)	0.94 (0.318)**	-0.47 (0.22)*
Fat score[c]	-1.5 (0.376)***	-0.01 (0.02) -0.08 (0.023)**	0.52 (0.415)	-0.04 (0.012)**	-0.78 (0.373)*	1.04 (0.249)***
Live weight gain/day of age (g)	70 (33)*	4 (1.0)***	196 (43)*** 50 (47)	4 (1.0)***	-23 (31.6)	16 (22.3)
Carcass gain/day of age (g)	53 (17)**	1 (0.7)	90 (24)*** -3 (27)	2 (0.5)***	20 (17)	-4 (12.2)

[a]Where the associations differed significantly by system, the solutions are both presented as bulls and steers, from left to right
[b]EU Beef Carcass Classification Scheme Scale 1 (poorest) to 15 (best)
[c]EU Beef Classification Scheme Scale 1 (leanest) to 15 (fattest)

EXPERIMENT 2: Live animal measurements, carcass composition and plasma hormone and metabolite concentrations in male progeny of sires differing in genetic merit for beef production

Introduction

Genetic improvement programmes for beef cattle are becoming increasingly important in order to increase economic returns for producers through production of carcasses with higher meat yield that better meet market demands. European market requirements demand lean carcasses of good conformation. Carcasses of high lean meat yield command the higher prices and therefore, breeding to achieve these targets is vital for long-term sustainability of the Irish beef industry (Drennan *et al.,* 2007). The Irish Cattle Breeding Federation (ICBF) launched economically weighted genetic selection indices for beef cattle in 2005 to aid farmers in comparing animals on genetic merit for the expected profitability of their progeny. The beef carcass index (BCI) estimates the genetic potential of a sire to generate profitable progeny for slaughter. Genetic evaluations in Ireland use purebred and crossbred data and expected progeny differences (EPD) are expressed across breeds.

The BCI is composed of five economically weighted traits (weaning weight, dry matter (DM) intake, carcass weight, carcass conformation score and carcass fat score). The efficacy of this economic index was first examined under a controlled environment in contrasting production systems and results showed that the observed differences in profitability of progeny of sires differing in BCI were in good agreement with the expected values (Clarke *et al.*, 2008). Furthermore, for each unit increase in sire EPD for weaning weight, DM intake, carcass weight, carcass conformation score and carcass fat score, progeny performance increased for each of the respective traits by 1.0 kg, 1.1 kg, 1.3 kg, 0.9 (scale 1 to 15) and 1.0 (scale 1 to 15); none of which differed from the theoretical expectation of unity.

Carcass meat yield and distribution are the ultimate indicators of carcass value and are therefore imperative to genetic improvement programmes. Live animal indicators of carcass meat yield and distribution include visual muscularity and skeletal scores (Drennan *et al*., 2008). These indicators are particularly important in pedigree breeding programmes because carcass data will not be available on those animals. Linear muscularity and skeletal scoring (visual assessment) is envisaged to form an integral part of early carcass merit prediction in the BCI (Evans *et al.*, 2007). Consequently, the correlated responses to selection on the BCI for live animal measurements and carcass composition should be investigated. Because energy metabolism in skeletal muscle is under strong endocrinological control (Florini *et al.,* 1997) the use of systemic concentrations of key metabolic hormones and metabolites may be of potential use to increase the accuracy of genetic selection for growth and meat quality (Hocquette *et al.,* 1998). For example, circulating concentrations of IGF-1 has been positively associated with feed efficiency (Stick *et al.,* 1998; Arthur and Herd, 2005), weaning weight and post-weaning gain (Davis and Simmen, 1997; Stick *et al.*, 1998).

The objective of this study was to quantify the effect of sire genetic merit for BCI on live animal scores, carcass composition and plasma hormone and metabolite concentrations in their progeny reared under either bull or steer production systems.

Material and Methods

Study design

Male progeny from 22 late-maturing beef breed sires selected as either high (n=11) or low (n=11) for the Irish genetic index, BCI, were purchased between October 2005 and January 2006. The BCI of a sire is the sum of the product of the economic weight and respective EPD for each of five individual traits and thus, is related to the expected profitability of the progeny at slaughter. Traits (relative emphasis with sign of economic weight included in parenthesis) included in the BCI in 2008 were weaning weight (+0.24), dry matter (DM) intake (-0.12), carcass weight (+0.46), carcass conformation score (+0.11) and carcass fat score (-0.07).

Within both the high and low genetic merit groups there were 5 Charolais, 3 Limousin, 2 Simmental and 1 Belgian Blue sires (Table 1). Details of the BCI values for each sire and the EPD for weaning weight (EPD_{WWT}), DM intake (EPD_{DMI}), carcass weight (EPD_{CWT}), carcass conformation score (EPD_{CONF}) and carcass fat score (EPD_{FAT}) are summarised in Table 1. The values used are from the ICBF February 2008 genetic evaluation run. Expected progeny differences are expressed in their units of measurement with weaning weight, daily DM intake and carcass weight measured in kg, and both carcass conformation and fat score measured separately according to the EU beef carcass classification scheme (Commission of the European Communities, 1982) on a scale of 1 (poor conformation and low fat cover) to 15 (good conformation and high fat cover) as outlined by Hickey *et al.* (2007). The weighted mean difference in BCI between the high and low genetic merit sires was €42. On average, the advantage of the high over the low BCI sires was 6 kg in sire EPD_{WWT}, -0.02 kg in sire EPD_{DMI}, 13

kg in sire $EPD_{CWT,}$ 0.24 in sire EPD_{CONF} and -0.44 in sire EPD_{FAT}. All sires were proven in Ireland and had reliabilities associated with their BCI values ranging from 91% to 99% with a mean value of 96%. Reliability of sire EPD for the individual traits ranged from 78% to 99% with a mean value of 93%.
The progeny originated from 28 commercial suckler beef herds with the number of purchased progeny per herd varying from 1 to 10. Animals were primarily born in spring to a multiparous dam and reared on their dam at pasture until weaning at approximately 8 months of age. For the purpose of the analysis in the present study, breed of dam was separated into 4 groups: 1) Limousin and Limousin cross; 2) Simmental and Simmental cross; 3) Aberdeen Angus and Hereford with their associated crosses; and 4) Belgian Blue and Charolais with their associated crosses.
The purchased weanlings were assembled at the Grange Beef Research Centre, where they remained for the duration of the study until slaughter. Paternal verification of each animal purchased was determined using 11 DNA-markers including the 9 microsatellite markers recommended by the International Society of Animal Genetics (International Society of Animal Genetics, 2008) and only animals with a positive paternal test outcome were retained. A total of 107 animals were included in the study. Number of progeny per sire varied from 1 to 10 with a mean number of 5.

Animal management
Upon arrival at the research centre, all animals were vaccinated as a prophylaxis against respiratory disease and treated for the control of ecto- and endo-parasites. They were offered grass silage *ad libitum* plus 2 kg of supplementary concentrate over the pre-experimental period. While trying to maintain an equal number of progeny per sire, each animal was randomly allocated to one of two production systems; an "intensive" bull production system with slaughter age at approximately 16 months or an "extensive" steer production system with slaughter at approximately 24 months. As some animals were already castrated on arrival, castration of the remaining animals destined for the steer production system took place at this time. A total of 50 bulls and 57 steers were used in the study.
Bulls were individually offered a barley-based concentrate diet *ad libitum* using calan-broadbent gates until slaughter on 26 June 2006 as described by Clarke *et al.* (2009). Steers were offered grass silage *ad libitum* and a concentrate supplement for most of the winter and were turned out to pasture on the 18 April. They remained at pasture until 18 October 2006 when they were re-housed and individually offered grass silage until 22 December 2006. Concentrates were then introduced to the diet and this diet was available *ad libitum* in addition to 1 kg of grass silage DM per head daily from January 2007 until slaughter on 13 or 27 April 2007 as described by Clarke *et al.* (2009). The steers were slaughtered in two groups for logistical reasons and were balanced for genetic merit and as far as possible for sire on each slaughter date. Slaughter of all animals was carried out in the same commercial meat plant.

Animal measurements
Animals were weighed on 5 January 2006 having received a standard diet from the time of arrival at the research centre. This weight is referred to as live weight after weaning. Bulls were subsequently weighed at 28 d intervals from then until slaughter resulting in a total number of 7 weight records per bull. Steers were also weighed at 28 d intervals from the initial weight to housing in October 2006 after which they were weighed every 14 d until slaughter in April 2007 resulting in a total number of 27 weight records per steer. Weighing always occurred prior to the morning feeding or when at pasture prior to movement to the next paddock in the rotation.
Both bulls and steers were visually assessed for muscularity traits using the Signet (Allen, 1990) and ICBF (ICBF, 2002) scoring procedures in January 2006. Skeletal scores were also recorded at the same time using the ICBF linear scoring system (ICBF, 2002). These scores were taken to represent weanling live score assessments. Each animal was also scored for the same traits in the week pre-slaughter. The Signet scoring system assigns visual muscularity scores to each animal at 3 different locations namely roundness of hind-quarter, width of rump and the thickness/width at the loin. The system uses a scale of 1 to 15 where 1 represents low and 15 represents high degree of muscularity. Each location was given a single score and then the 3 scores were averaged to give a single value for muscularity both after weaning and pre-slaughter by the same assessor.
Muscularity scores using the ICBF linear scoring system involved visual assessment at 6 different locations namely width at withers, width behind withers, loin development, development of hind-quarter, width at hind-quarter, and development of the inner thigh. The muscularity traits were again scored on a scale of 1 to 15, with 1 for poor and 15 for excellent muscularity development. These muscularity scores were then averaged to give one overall muscularity score. The 3 skeletal traits assessed were height at withers, length of back and pelvic length. The skeletal traits were scored on a scale of 1 (short) to 10 (extended). The ICBF muscularity and skeletal scores were all carried out by one person.
At the same time as muscularity scoring, each animal was ultrasonically scanned to obtain *longissimus dorsi* muscle depth and depth of back fat using a dynamic imaging Ultrasound scanner (model - Concept/MCV, with

3.5 MHz head). Muscle depth was measured at the 3rd lumbar vertebra. Four fat depth measurements were taken at the 13th rib and a further three at the 3rd lumbar vertebra. These values were subsequently combined and an average value calculated.
The bulls were blood sampled by jugular venipunture on three occasions (1 February, 17 May and 21 June 2006 which corresponds to day -14, 94 and 129 of the concentrate feed intake period) when offered a high level of concentrates (day -14) or concentrates *ad libitum* (days 94 and 129). The steers were also blood sampled 3 times during the *ad libitum* concentrate feeding period (1 February, 6 March, and 29 March 2007 which corresponds to days 11, 44 and 67 of the *ad libitum* concentrate feeding period). On each sampling occasion 4 samples were taken from each animal using 3 lithium heparin (9 ml) and 1 sodium fluoride (4 ml) evacuated blood collection vials. Samples were centrifuged at ~ 2000 × g for 15 minutes and the resulting plasma poured into plastic 5 ml borosilicate glass scintillation vials and stored at -20°C until analysis. Plasma urea, glucose, non-esterified fatty acids (NEFA), cholesterol and beta-hydroxybutyrate (βHB) concentrations were measured on an automatic analyser (Olympus AU 400, Tokyo, Japan) using the reagent kits supplied by Olympus. Plasma concentrations of insulin were quantified using fluoro-immunassay (AutoDelfia insulin assay). Intra-assay coefficients of variation (CV) for insulin in bull samples were 6.6%, 4.4% and 2.5% for the low, medium and high standards, respectively and only one assay was required in the bull analysis. Intra-assay CVs for insulin in steer samples were 4.4%, 4.6% and 4.3% for the low, medium and high standards, respectively. Corresponding, inter-assay CVs were 4.5%, 4.6% and 4.3%. Plasma concentrations of IGF-I were quantified using radio-immuno assay following an acid ethanol extraction. Intra-assay CVs for IGF-1 in bull and steer samples were 16.7%, 10.6% and 12.9% for low, medium and high standards, respectively. Inter-assay CVs were 17.2%, 10.9% and 12.9% for low, medium and high standards, respectively.
At slaughter, kidney and channel fat was removed from each carcass and weighed. Hot carcass weight was then recorded and cold carcass weight was taken as 0.98 of hot weight. After 24 h at 4 °C, the right side of each carcass was dissected into meat, fat and bone. The side was quartered at the 5th rib into an eight-rib hind-quarter (pistola) and a fore-quarter. The hind-quarter consisted of 13 cuts (silverside, topside, knuckle, rump, cap of rump, tail of rump, fillet, striploin, cube roll, leg, heel, cap of rib, eye of round) and the fore-quarter consisted of 11 cuts (braising muscle, bladesteak, clod, chuck tender, brisket, front shin, flat ribs (rib 1 to 5), plate, chuck, neck, *m. triceps brachii*). All dissectible fat was removed and where applicable, bones were also removed and cleaned of all adhering tissue. Each meat cut was weighed and recorded separately. Bone, fat and lean trim (small pieces of meat cut away from bone and fat in the dissection process) were recorded separately for the fore- and hind-quarters. Lean trim was subsequently combined with the meat cuts to give meat yield. The combined weights of meat in the fillet, striploin and cube roll was taken to represent the high-value cuts (HVC) in the carcass. This was expressed both as a proportion of the half carcass weight (HVC_C) and as a proportion of the half carcass meat weight (HVC_M). Calculated carcass value, expressed as cent per kg carcass, was the sum of the commercial value of each meat cut (cent/kg multiplied by the corresponding weight of the cut) with a small deduction for bone expressed as a proportion of the half carcass weight. Estimated animal value (€) was calculated as cold carcass weight (kg) multiplied by calculated carcass value (cent/kg) divided by 100.

Using the five individual traits of the BCI, the observed phenotypic profit measure (€) was calculated for each individual animal using the following series of steps. The phenotypic performance for all five BCI traits of one random animal from the experiment were taken and all animals were then expressed relative to the performance of this animal by subtraction of the chosen animal's performance from all the trial animals. These new relative performances for each trait were then multiplied by the economic value for the trait as used in the BCI and summed to yield the actual relative profit (€). Thus, the chosen animal's performance became the basis of comparison with a zero for all traits. The economic values used in this calculation were the same as those used in the February 2008 release of proofs for the calculation of the BCI. These were €1.04 per kg increase in weaning weight, -€21.94 per kg increase in DM intake consumed, €2.34 per kg increase in cold carcass weight, €10.74 per unit increase in carcass conformation score (scale of 1-15) and -€6.08 per kg increase in carcass fat score (scale of 1-15). The observed difference in value for the progeny of the high and low BCI sires, for each of the five component traits was then expressed as a proportion of the total difference in value. The same analysis was carried out on the sire EPD (as in Table 1) with the expected difference in value between the high and low EPDs for each of the five component traits also was expressed as a proportion of the total difference in value.

Statistical analysis
The associations among genetic merit for BCI, production system and the live animal measurement and carcass trait variables were determined using a fixed effect linear model in PROC GLM (SAS, 2008). Both genetic merit and production system were treated as class variables. Confounding variables adjusted for in the model of analyses where significant ($P<0.05$) were sire breed, dam breed, dam parity and age at the time of the

measurement centered within production system. Age centered within production system was treated as a continuous variable.
Preliminary analyses of the plasma hormone and metabolite data revealed that some of the variables were not normally distributed. Therefore, the natural logarithm transformation of insulin, glucose, βHB and IGF-1 were used to normalise the distributions. The associations among genetic merit for BCI, production system and hormone and metabolite variables was determined using mixed models (SAS, 2008) with animal included as a repeated effect. A compound symmetry covariance structure was assumed among records within animal. Confounding variables adjusted for in the model were the same as those already applied except day of blood sampling nested within production system.
Non-linear associations between age and the dependent variables as well as the possible existence of an interaction between genetic merit and production system were also tested for in the models.
An additional series of analyses was undertaken whereby the independent variable, genetic merit was included as a continuous variable, with genetic merit defined as one of each of the following: sire BCI, EPD_{WWT}, EPD_{DMI}, EPD_{CWT}, EPD_{CONF}, and EPD_{FAT}. Where the dependent variable was live animal measurements or carcass traits, a fixed effect linear model was used. A mixed model was used to quantify the association between sire EPD for the different traits and the plasma hormone and metabolites with animal included as a repeated effect. Non-linear associations between genetic merit and the dependent variable and interactions between genetic merit and production system were also investigated. Sire breed was not included in this analyses as genetic evaluations in Ireland are undertaken and presented across breeds.

Results

Live animal measurements
The effect of BCI, when treated as a class variable and production system (bulls and steers) on live animal measurements after weaning and pre-slaughter is summarised in Table 2. The effect of BCI on live animal traits was consistent across both production systems. Progeny of high BCI sires had greater (P<0.01) ICBF muscularity scores and greater (P<0.05) skeletal scores after weaning. There was no significant difference in Signet muscularity score or scanned muscle and fat depths between high and low BCI progeny after weaning. Pre-slaughter, there was no significant difference in Signet and ICBF muscularity scores, length of pelvis or scanned fat depth between high and low BCI progeny. However, height at withers, length of back and scanned muscle depth was greater (P<0.05) for progeny of high BCI sires than those of low BCI sires.
Bulls had greater (P<0.001) scanned muscle depth than steers, however there was no significant difference in any of the other traits measured after weaning. Pre-slaughter, bulls had lower (P<0.001) live weight, skeletal scores and scanned muscle and fat depths but greater (P<0.001) muscularity scores than steers.
The effect of a €100 increase in sire BCI and a unit increase in sire EPD_{WWT}, EPD_{DMI}, EPD_{CWT}, EPD_{CONF} and EPD_{FAT} on progeny live animal measurements are summarised in Table 3. There were no non-linear effects between any genetic merit traits (BCI and EPDs) and live animal scores observed although the associations sometimes differed between bulls and steers. The ICBF muscularity score after weaning, and Signet and ICBF muscularity scores and height at withers pre-slaughter, increased (P<0.05) with increasing BCI The effect of BCI on scanned fat depth pre-slaughter differed with production system with no significant association observed in bulls and a negative (P<0.001) association in steers. There was no significant effect of BCI on Signet muscularity score, skeletal scores and scanned muscle and fat depths after weaning or on length of back, length of pelvis and scanned muscle depth pre-slaughter.
Pre-slaughter skeletal scores increased (P<0.05) with increasing sire EPD_{WWT}. The effect of sire EPD_{WWT} on height at withers and length of pelvis after weaning differed with production system with a positive (P<0.05) effect in bulls and no significant effect in steers. Scanned fat depth pre-slaughter also differed with production system with no significant effect in bulls and a negative (P<0.05) effect in steers. Pre-slaughter skeletal scores and scanned fat depth increased (P<0.01) and Signet muscularity score decreased (P<0.01) with increasing sire EPD_{DMI}. The effect of increasing sire EPD_{DMI} on height at withers, length of back, scanned muscle depth after weaning were significant in bulls but not in steers.
The ICBF muscularity score and height at withers after weaning, and skeletal scores and scanned muscle depth pre-slaughter increased (P<0.05) with increasing sire EPD_{CWT}. Sire EPD_{CWT} was not significantly associated with pre-slaughter scanned fat depth in bulls but was negatively (P<0.01) associated in steers. The ICBF muscularity score after weaning and pre-slaughter, and the Signet score pre-slaughter increased (P<0.05), whereas scanned fat depth pre-slaughter decreased (P<0.01) with increasing sire EPD_{CONF}. After weaning the effect of sire EPD_{CONF} on Signet muscularity score differed with production system with a positive (P<0.01) effect in bulls and no significant effect in steers. Height at withers measured at weaning also differed with production system with increasing sire EPD_{CONF}, in that there was no significant effect in bulls and a positive effect (P<0.05) in steers. Pre-slaughter, Signet and ICBF muscularity scores decreased (P<0.05), whereas scanned fat depth increased (P<0.001) with increasing sire EPD_{FAT} in both production system.

Carcass composition

The effect of BCI, when treated as a class variable and production system on progeny carcass composition are summarised in Table 4. Animal value of progeny of high BCI sires was €59 higher ($P<0.05$) than the progeny of low BCI sires. There was no significant difference between the two genetic groups (high or low BCI) for kidney and channel fat, carcass meat, fat or bone proportions, HVC_C and HVC_M or calculated carcass value. Bulls had lower ($P<0.001$) kidney and channel fat, carcass fat proportion and animal value, and higher ($P<0.001$) carcass meat and bone proportions, HVC_C, HVC_M and calculated carcass value than steers. The effect of BCI on carcass traits was consistent across both production systems with the exception of HVC_C, calculated carcass value and animal value. The significant BCI by production system interaction for these 3 traits was due to the steer progeny of low BCI sires having lower HVC_C, carcass value and animal value than the steer progeny of high BCI sires, while the opposite occurred in bulls.

The effect of a €100 increase in sire BCI and a unit increase in sire EPD_{WWT}, EPD_{DMI}, EPD_{CWT}, EPD_{CONF} and EPD_{FAT} on progeny carcass composition are summarised in Table 5. The effect of BCI on carcass meat proportion, HVC_C, calculated carcass value and estimated animal value differed with production system with no significant effect in bulls and a positive ($P<0.01$) effect in steers. Carcass fat proportion also differed with production system with no significant effect of BCI in bulls and a negative ($P<0.01$) effect in steers.

Sire EPD_{WWT} was negatively ($P<0.05$) associated with calculated carcass value in bulls whereas there was no significant effect in steers. Kidney and channel fat and carcass fat and bone proportions increased ($P<0.05$), whereas carcass meat proportion, HVC_C and calculated carcass value decreased ($P<0.05$) with increasing EPD_{DMI}.

The effect of sire EPD_{CWT} on carcass meat proportion, HVC_C, HVC_M, calculated carcass value and estimated animal value differed with production system with no significant effect of BCI in bulls and a positive ($P<0.05$) effect in steers, and on carcass fat proportion with no significant effect in bulls and a negative ($P<0.05$) effect in steers.

Kidney and channel fat, and carcass fat and bone proportions decreased ($P<0.05$), whereas carcass meat proportion, HVC_C, calculated carcass value and estimated animal value increased ($P<0.05$) with increasing sire EPD_{CONF}.

Carcass meat proportion, HVC_C and calculated carcass value decreased ($P<0.05$), whereas carcass fat proportion increased ($P<0.01$) with increasing sire EPD_{FAT}. The effect of sire EPD_{FAT} on estimated animal value differed with production system with no significant effect in bulls and a negative ($P<0.05$) effect in steers.

Plasma metabolites and hormones

Progeny of high BCI sires had lower ($P<0.05$) insulin concentrations than progeny of low BCI sires (Table 6). There was no difference in plasma cholesterol, urea, NEFA, glucose, βHB or IGF-1 concentrations between the two genetic groups (high or low BCI). Bulls had higher ($P<0.05$) glucose, NEFA and IGF-1 concentrations and lower ($P<0.05$) cholesterol, urea, and insulin concentrations compared with steers. There was no difference in βHB concentration between bulls and steers.

There were no significant associations between BCI, EPD_{WWT} or EPD_{CWT} and plasma cholesterol, urea NEFA, glucose, βHB or insulin concentrations (Table 7). Urea concentrations increased, whereas βHB concentrations decreased with increasing sire EPD_{DMI}. Cholesterol and βHB increased ($P<0.05$) with increasing sire EPD_{CONF}, whereas βHB decreased ($P<0.05$) with increasing sire EPD_{FAT}. IGF-1 concentrations decreased ($P<0.05$) with increasing BCI, EPD_{WWT}, EPD_{DMI} and EPD_{CWT}.

Conclusions

In conclusion, results from this study show that selection using the BCI had a positive effect on live animal muscularity scores, carcass meat proportion, proportion of HVC_C and carcass value in steer progeny, which are all very desirable traits in beef production, and no effect on the plasma metabolites measured. Based on carcass meat proportion, the indicators of which in the BCI are conformation and fat scores, findings in the present study would suggest that they should receive greater weightings within beef cattle genetic selection indices such as the BCI.

Implications

The present results indicate that selection using the Beef Carcass Index does not have any adverse effects on important and desirable traits (such as live animal muscularity, carcass meat proportion and carcass value) in beef production and greater emphasis on indicators of carcass meat proportion (i.e. conformation and fat scores) should be included in the Beef Carcass Index.

Table 1. Values for the beef carcass index (BCI), expected progeny differences for weaning weight (EPD_{WWT}), dry matter intake (EPD_{DMI}), carcass weight (EPD_{CWT}), carcass conformation score (EPD_{CONF}) and carcass fat score (EPD_{FAT}) for sires of high and low BCI used in the study

Sire	Breed	BCI (€100)	EPD_{WWT} (kg)	EPD_{DMI} (kg)	EPD_{CWT} (kg)	EPD_{CONF} (score) [a]	EPD_{FAT} (score) [b]
High BCI sires							
VDC	BB	142	9.79	-0.43	36.92	2.52	-1.44
CF52	CH	162	20.72	-0.05	46.94	2.04	-1.33
HWN	CH	150	14.65	0.02	45.11	2.14	-1.15
HKI	CH	146	8.65	-0.04	45.84	2.05	-1.07
MDO	CH	140	19.91	0.29	41.99	2.09	-0.84
NXB	CH	124	12.24	0.24	40.69	1.68	-0.52
ROX	LM	122	6.64	-0.20	34.33	2.46	-0.73
ORO	LM	89	6.52	-0.26	22.05	1.91	-0.66
NIN	LM	79	0.24	-0.17	22.02	2.00	-0.39
HKG	SI	107	11.29	0.26	34.70	1.55	-0.56
MLM	SI	89	17.79	0.6	28.10	1.59	-0.20
Weighted Mean		129	12.5	0.04	38.5	2.00	-0.84
Low BCI sires							
NRO	BB	93	-1.89	-0.42	21.56	2.70	-1.01
NWK	CH	122	21.48	0.46	38.03	1.70	-0.49
CF57	CH	114	17.49	0.21	33.89	1.62	-0.67
NBC	CH	96	6.93	-0.45	22.14	1.77	-1.31
CF43	CH	95	1.88	0.31	33.98	1.99	0.12
KFC	CH	92	6.39	0.47	32.19	1.83	-0.16
DGA	LM	53	-9.44	-0.36	14.34	1.99	-0.02
PTS	LM	46	-5.78	-0.62	7.45	1.66	-0.45
LUR	LM	45	-3.33	-0.22	10.69	1.75	0.02
BDJ	SI	66	15.48	0.44	20.04	1.26	0.09
HRG	SI	61	7.82	0.29	18.08	1.31	-0.50
Weighted Mean		87	6.7	0.06	25.5	1.76	-0.40

[a]EU Beef Carcass Classification Scheme Scale 1 (poorest) to 15 (best)
[b]EU Beef Classification Scheme Scale 1 (leanest) to 15 (fattest)
BB = Belgian Blue; CH = Charolais; LM = Limousin; SM = Simmental

Table 2. Effect of sire beef carcass index (BCI) and production system on live animal measurements after weaning and before slaughter

	BCI			Production System (PS)			Significance[a,b]	
	High	Low	s.e.d.	Bulls	Steers	s.e.d.	BCI	PS
Weaning								
Live weight (kg)	374	357	9.1	364	367	9.1	ns	ns
Signet muscular score[c]	7.0	6.71	0.273	7.08	6.64	0.275	ns	ns
ICBF muscular score[d]	7.5	6.9	0.239	7.2	7.1	0.241	**	ns
Height at withers[e]	5.5	5.0	0.17	5.3	5.2	0.17	**	ns
Length of back[e]	5.8	5.4	0.17	5.5	5.7	0.17	*	ns
Length of pelvis[e]	5.5	5.1	0.17	5.1	5.5	0.17	*	ns
Scanned muscle depth, (mm)	60.5	59.3	1.27	62.4	57.3	1.27	ns	***
Scanned fat depth, (mm)	1.1	1.1	0.05	1.1	1.1	0.05	ns	ns
Slaughter								
Live weight (kg)	681	662	13.0	619	724	13.0	ns	***
Signet muscular score[c]	8.9	8.6	0.32	9.1	8.4	0.32	ns	*
ICBF muscular score[d]	9.8	9.6	0.19	10.0	9.3	0.19	ns	***
Height at withers[e]	7.8	7.2	0.20	6.8	8.2	0.21	**	***
Length of back[e]	7.9	7.6	0.17	7.2	8.3	0.17	*	***
Length of pelvis[e]	7.5	7.2	0.18	6.8	7.9	0.18	ns	***
Scanned muscle depth, (mm)	77.0	74.3	1.10	72.7	78.5	1.10	*	***
Scanned fat depth, (mm)	3.2	3.4	0.29	2.0	4.6	0.29	ns	***

[a]Significance levels: ***P<0.001; ** = P<0.01; * = P<0.05; ns = P>0.05
[b]There were no significant BCI × PS interactions
[c]Signet Scoring Procedure; average of 3 locations, scale 1 (hollow, narrow conformation) to 15 (wide, thick muscled)
[d]Irish Cattle Breeding Federation muscular scoring system; average of 6 locations, scale 1 (hollow, narrow conformation) to 15 (wide, thick muscled)
[e]Skeletal scores, scale 1 (short) to 10 (extended)

Table 3. Regression co-efficients (s.e) for beef carcass index (BCI), expected progeny differences for weaning weight (EPD_{WWT}), dry matter intake (EPD_{DMI}), carcass weight (EPD_{CWT}), conformation score (EPD_{CONF}) and fat score (EPD_{FAT}) on live animal measurements after weaning and before slaughter[a]

	BCI (/€100)	EPD_{WWT} (kg)	EPD_{DMI} (kg)	EPD_{CWT} (kg)	EPD_{CONF} (score) [b]	EPD_{FAT} (score) [c]
Weaning						
Live weight (kg)	18.5 (13.5)	1.0 (0.53)*	35.4 (13.88)*	0.8 (0.43)*	0.6 (12.78)	3.1 (9.12)
Signet muscular score[d]	0.58 (0.367)	0.01 (0.015)	-0.10 (0.390)	0.02 (0.012)	1.6 (0.493)** 0.23 (0.455)	-0.3 (0.247)
ICBF muscular score[e]	0.98 (0.331)**	0.01 (0.014)	-0.20 (0.355)	0.03 (0.011)**	1.02 (0.301)**	-0.41 (0.224)
Height at withers[f]	0.37 (0.238)	0.03 (0.012)* -0.01 (0.014)	1.06 (0.312)*** -0.50 (0.35)	0.02 (0.008)*	-0.58 (0.317) 0.66 (0.296)*	-0.01 (0.157)
Length of back[f]	0.13 (0.251)	0.01 (0.01)	0.94 (0.335)** -0.09 (0.375)	0.01 (0.008)	-0.23 (0.236)	0.18 (0.163)
Length of pelvis[f]	0.18 (0.259)	0.03 (0.013)* -0.02 (0.015)	0.42 (0.265)	0.01 (0.008)	-0.05 (0.245)	0.07 (0.169)
Scanned muscle depth, (mm)	2.42 (1.917)	0.08 (0.076)	6.19 (2.594)* -2.39 (2.934)	0.10 (0.062)	1.38 (1.775)	-0.5 (1.276)
Scanned fat depth, (mm)	0.063 (0.0711)	0.003 (0.0028)	0.108 (0.0727)	0.003 (0.0022)	-0.01 (0.0663)	0.014 (0.0472)
Slaughter						
Live weight (kg)	39.2 (18.59)*	1.8 (0.72)*	93.5 (24.51)*** 21.1 (27.52)	1.9 (0.59)**	-14.8 (17.87)	1.2 (12.39)
Signet muscular score[d]	1.075 (0.4382)*	-0.001 (0.0178)	-1.268 (0.4414)**	0.022 (0.0142)	1.377 (0.4068)**	-0.955 (0.2783)**
ICBF muscular score[e]	0.493 (0.2453)*	0.003 (0.0099)	-0.388 (0.2517)	0.011 (0.0079)	0.581 (0.2310)*	-0.403 (0.1581)*
Height at withers[f]	0.63 (0.286)*	0.03 (0.011)**	0.88 (0.295)**	0.03 (0.009)**	-0.21 (0.274)	0.01 (0.196)
Length of back[f]	0.42 (0.241)	0.03 (0.009)**	0.84 (0.243)***	0.02 (0.008)**	-0.38 (0.226)	0.11 (0.164)
Length of pelvis[f]	0.41 (0.267)	0.02 (0.01)*	0.78 (0.27)**	0.02 (0.009)*	-0.14 (0.255)	0.15 (0.176)
Scanned muscle depth, (mm)	3.20 (1.655)	0.06 (0.066)	1.18 (1.711)	0.12 (0.052)*	1.25 (1.599)	-1.13 (1.093)
Scanned fat depth, (mm)	-0.44 (0.526) -2.36 (0.555)***	0.02 (0.021) -0.06 (0.024)*	1.2 (0.411)**	-0.01 (0.017) -0.06 (0.019)**	-1.01 (0.377)**	1.06 (0.255)***

[a]Where the associations differed significantly by system, the solutions are both presented as bulls and steers from left to right
[b]EU Beef Carcass Classification Scheme Scale 1 (leanest) to 15 (best)
[c]EU Beef Carcass Classification Scheme Scale 1 (poorest) to 15 (fattest
[d]Signet Scoring Procedure, an average of 3 locations, scale 1 (hollow, narrow conformation) to 15 (wide, thick muscled)
[e]Irish Cattle Breeding Federation muscular scoring system, an average of 6 locations, scale 1 (hollow, narrow conformation) to 15 (wide, thick muscled)
[f]Skeletal scores, scale 1(short) to 10 (long)

Table 4. Effect of sire beef carcass index (BCI) and production system on carcass composition and value

	BCI			Production System (PS)			Significance[a]		
	High	Low	s.e.d.	Bulls	Steers	s.e.d.	BCI	PS	BCI × PS
Carcase weight (kg)	390	376	6.67	353	413	6.67	*	***	ns
K & C Fat (g/kg)	7.8	9.6	1.07	7.2	10.2	1.08	ns	***	ns
Meat (g/kg)	718	713	6.55	726	705	6.55	ns	***	ns
Fat (g/kg)	107	112	5.78	94	124	5.79	ns	***	ns
Bone (g/kg)	174	175	2.42	180	170	2.44	ns	***	ns
HVC_C [b,c], (g/kg)	70	70	1.17	73	66	1.17	ns	***	*
HVC_M [d] (g/kg)	99	98	1.21	102	95	1.21	ns	***	ns
Calculated carcass value[e,f] (c/kg)	305.7	302.2	3.42	312.0	295.9	3.43	ns	***	*
Animal value[g] (€)	1188	1129	25.7	1106	1211	25.7	**	***	*

[a]Significance levels: ***P<0.001; * = P<0.05; ns = P>0.05, [b]High-value cuts expressed as a proportion of the carcass. [c]BCI × PS interaction values: high BCI; 72, 67 and low BCI; 74, 64 for bulls and steers, respectively. [d]High-value cuts expressed as a proportion of the meat (i.e., excluding bone and fat). [e]The sum of the commercial value of each meat cut with a small deduction for bone expressed as a proportion of the half carcass weight. [f]BCI × PS interaction values: high BCI; 310, 300 and low BCI; 313, 290 for bulls and steers, respectively. [g]BCI × PS interaction values: high BCI; 1106, 1262 and low BCI; 1107, 1152 for bulls and steers, respectively

Table 5. Regression co-efficients (s.e) for beef carcass index (BCI), expected progeny differences for weaning weight (EPD_{WWT}), dry matter intake (EPD_{DMI}), carcass weight (EPD_{CWT}), conformation score (EPD_{CONF}) and fat score (EPD_{FAT}) on carcass composition and value[a]

	BCI (/€100)	EPD_{WWT} (kg)	EPD_{DMI} (kg)	EPD_{CWT} (kg)	EPD_{CONF} (score) [b]	EPD_{FAT} (score) [c]
Carcass weight (kg)	30.9 (9.83)**	0.8 (0.4)*	40.7 (13.66)** -4.9 (15.33)	1.3 (0.31)***	11.0 (9.66)	9.0 (9.45) -19 (9.22)*
Kidney & channel fat, (kg)	-1.68 (1.506)	0.04 (0.059)	3.40 (1.56)*	-0.03 (0.049)	-3.31 (1.383)*	1.65 (1.002)
Meat, (g/kg)	-1.3 (11.84) 40.2 (12.72)**	-0.9 (0.46) 0.6 (0.53)	-31.5 (8.88)***	-0.3 (0.37) 1.1 (0.42)*	32.0 (8.22)***	-16.4 (5.79)**
Fat, (g/kg)	-1.8 (10.21) -34.4 (10.97)**	-0.0 (0.31)	20.9 (7.84)**	0.1 (0.34) -0..9 (0.36)*	-21.9 (7.28)**	13.5 (5.00)**
Bone, (g/kg)	-3.6 (3.32)	0.2 (0.13)	8.2 (3.43)*	-0.1 (0.11)	-10.4 (3)***	2.8 (2.23)
HVC_C [d], (g/kg)	-0.88 (2.048) 7.74 (2.201)***	-0.04 (0.063)	-4.87 (1.576)**	-0.06 (0.063) 0.25 (0.072)***	3.23 (1.511)*	-2.33 (1.027)*
HVC_M [e], (g/kg)	2.15 (1.792)	-0.01 (0.071)	-2.23 (1.87)	-0.04 (0.074) 0.21 (0.084)*	0.12 (1.72)	-1.18 (1.205)
Calculated carcass value[f], (c/kg)	-0.3 (6.07) 26 (6.52)***	-0.5 (0.24)* 0.4 (0.28)	-17.3 (4.65)***	-0.2 (0.19) 0.8 (0.22)***	17.0 (4.3)***	-9.0 (3)*
Animal value (€)	61 (43.2) 235 (45.8)***	2 (1.4)	-10 (37.5)	3 (1.3) 8 (1.5)***	101 (32.8)**	3 (31.6) -115 (31.3)***

[a]Where the associations differed significantly by system, the solutions are both presented as bulls and steers from left to right
[b]EU Beef Carcass Classification Scheme Scale 1 (leanest) to 15 (best). [c]EU Beef Carcass Classification Scheme Scale 1 (poorest) to 15 (fattest)
[d]High-value cuts expressed as a proportion of the carcass. [e]High-value cuts expressed as a proportion of the meat i.e., excluding bone and no value on fat
[f]The sum of the commercial value of each meat cut with a small deduction for bone expressed as a proportion of the half carcass weight

Table 6. Effect of sire beef carcass index (BCI) and production system on plasma metabolites & hormones

	BCI			Production system (PS)			Significance	
	High	Low	s.e.d.	Bull	Steer	s.e.d.	BCI	PS
Cholestrol (mmol/L)	2.09	2.06	0.078	1.85	2.31	0.079	ns	***
Urea (mmol/L)	3.48	3.65	0.133	3.40	3.73	0.133	ns	*
NEFA (mmol/L)	0.13	0.11	0.010	0.14	0.10	0.010	ns	***
Log_e Glucose	1.55	1.53	0.019	1.56	1.52	0.019	ns	*
Glucose (mmol/L)	4.70	4.61		4.76	4.55			
Log_e βHB	-1.64	-1.63	0.058	-1.69	-1.58	0.058	ns	ns
βHB (mmol/L)	0.20	0.19		0.18	0.21			
Log_e Insulin	2.85	3.03	0.076	2.59	3.29	0.076	*	***
Insulin (uIU/ml)	17.26	20.73		13.38	26.76			
Log_e IGF-1	6.03	5.98	0.054	6.16	5.85	0.054	ns	***
IGF (pg/ml)	415	397		474	348			

(Back transformed least square means are presented where appropriate)
NEFA = Non-esterified fatty acids. βHB = Beta-hydroxybutyrate
[a]Significance levels: ***P<0.001; * = P<0.05; ns = P>0.05. [b]There were no significant BCI × PS interactions

Table 7. Regression co-efficient (standard errors in parenthesis) for beef carcass sub index, expected progeny differences for carcass weight (EPD^{CWT}), conformation (EPD_{CONF}) and fat (EPD_{FAT}) on plasma metabolites & hormones[a]

	BCI (/€100)	$EPD_{WWT}{}^{10}$ (kg)	$EPD_{DMI}{}^{10}$ (kg)	$EPD_{CWT}{}^{10}$ (kg)	$EPD_{CONF}{}^{10}$(score) [b]	$EPD_{FAT}{}^{10}$ (score) [c]
Cholesterol (mmol/L)	0.08(0.109)	-0.04(0.043)	-1.94(1.119)	0.01(0.035)	2.19(1.014)*	-0.8(0.727)
Urea (mmol/L)	-0.106(0.1984)	0.085(0.0783)	4.884(2.004)*	0.002(0.0631)	-3.282(1.853)	1.767(1.315)
NEFA (mmol/L)	0.02(0.016)	0.01(0.006)	0.05(0.159)	0.01(0.005)	0.12(0.149)	-0.06(0.102)
Log_e Glucose	-0.01(0.028)	0.01(0.011)	0.32(0.290)	0.01(0.009)	-0.29(0.265)	0.12(0.187)
Log_e βHB	0.11(0.086)	-0.02(0.034)	-2.13(0.871)*	0.02(0.027)	1.65(0.802)*	-1.2(0.565)
Log_e Insulin	-0.1(0.11)	-0.08(0.043)	-1(1.163)	-0.02(0.036)	-0.8(1.042)	0.43(0.743)*
Log_e IGF-1	-0.19(0.078)*	-0.12(0.029)***	-2.16(0.815)**	-0.07(0.025)**	0.72(0.749)	0.42(0.536)

[a]The associations did not differ with production system
[b]EU Beef Carcass Classification Scheme Scale 1 (leanest) to 15 (best). [c]EU Beef Carcass Classification Scheme Scale 1 (poorest) to 15 (fattest)
NEFA = Non-esterified fatty acids. βHB = Beta-hydroxybutyrate

EXPERIMENT 3: Intake, live animal scores/measurements and carcass composition and value of late-maturing beef and dairy breeds

Introduction

The main determinant of carcass price is meat yield and distribution. With more than 85% of Irish beef exported and a large variation in price across the various market outlets, the destination of exported product also influences price (Bord Bia, 2008). Higher-priced markets pay a premium for carcasses of good conformation and leanness. Therefore, producing cattle with these traits is of paramount importance and one of the main factors influencing feed intake, growth rate, carcass conformation and leanness is breed (Drennan and Keane, 2000; Keane and Drennan, 2008; Alberti et al., 2008). Additionally, as feed represents the single largest variable cost in beef production consequently, feed intake and efficiency are important traits. Live animal characteristics such as visual muscularity and skeletal scores are also useful in breed characterisation as early predictor traits, especially in animals selected for breeding programmes (Drennan et al., 2008). Visual muscularity and skeletal scores are envisaged to form an integral part of early carcass merit prediction in selection indexes such as the Irish Beef Carcass Index (Evans et al., 2007).

The source of the calf crop in Ireland is 2.29 million cows of which, 49% and 51% are dairy and beef suckler dams, respectively (Department of Agriculture, Fisheries and Food (DAFF), 2007). The dairy herd in Ireland consists predominantly of Holstein-Friesian cows of which, 52, 30 and 18% are bred to Holstein-Friesian, early-maturing beef (Aberdeen Angus and Hereford) and late-maturing beef sires, respectively (DAFF, 2007). The beef suckler cow herd consists of crossbreds of which, 71% are late-maturing breed crosses and 29% are early-maturing breed crosses. Eighty-four percent of beef dams are bred to late-maturing sire breeds of which, 40% are to Charolais, 30% to Limousin, 6% to Simmental and 4% to Belgian Blue (DAFF, 2007).

Although breeds for beef production were evaluated in the past (Southgate et al., 1982b; Kempster et al., 1982b; Keane, 1994; Hardy and Fisher, 1996) it is reasonable to assume that considering genetic improvement within beef breeds and particularly in dairy breeds, there is a need to re-examine differences between breeds across primary input and output traits. Furthermore, many contemporary breed comparison studies were confined to progeny from the dairy herd (Keane, 1994; McGee et al., 2005, 2007; Kirkland et al., 2007; Keane and Drennan, 2008) with a minority of studies comparing sire breeds from non-dairy dams. In the latter case, individual animal intake was not always measured (Alberti et al., 2008) and carcass composition was often estimated from rib joint dissection (Cuvelier et al., 2006; Alberti et al., 2008), which does not identify the distribution of meat cuts and thus, does not adequately reflect, carcass value. Many recent studies have examined meat quality characteristics between breeds (Chambaz et al., 2003; Cuvelier et al., 2006; Alberti et al., 2008) but there is limited information quantifying carcass value for the beef producer.

The objectives of this study were to compare the progeny of 1) late-maturing beef with dairy breeds and 2) Charolais (CH), Limousin (LM), Simmental (SM) and Belgian Blue (BB) sires bred to beef suckler dams, for feed intake, blood hormone and metabolites, live animal measurements, carcass traits and carcass value in bull and steer production systems.

Materials & Methods

Study design

Male progeny from 22 late-maturing beef sires selected as either high (n=11) or low (n=11) for the Irish genetic index, the Beef Carcass Index (BCI) (Evans et al., 2007) were purchased between October 2005 and January 2006 at approximately 8 to 10 months of age. The high and low BCI sires used in the present study each consisted of 5 Charolais (CH), 3 Limousins (LM), 2 Simmental (SM) and 1 Belgian Blue (BB). These numbers were representative of the sire breed proportions used on beef cows in Ireland in 2005. The progeny of the late-maturing beef sires originated from 28 commercial suckler beef herds. The number of animals purchased per herd varied from 1 to 10. Progeny were primarily born in spring to a multiparous dam and reared on its dam at pasture until weaning at approximately 8 months of age. Animal numbers by breed of sire were 56 CH (22 bulls, 34 steers), 23 LM (15 bulls, 8 steers), 18 SM (8 bulls, 10 steers) and 9 BB (5 bulls, 4 steers). Overall, the progeny averaged 91%, 84%, 90% and 87% of known late-maturing beef breed ancestry for CH, LM, SM and BB sires, respectively, with the remaining ancestry arising from early-maturing beef or dairy breeds. This was calculated using data supplied by the ICBF on breed fractions of the animals.

The Holstein (HO) bulls were purchased at approximately 3 weeks of age from commercial dairy farms while the Friesian (FR) steers were purchased at approximately 8 to 10 months of age from an artificial insemination station (Dovea Genetics, Thurles, Co. Tipperary, Ireland) and were originally assembled from commercial dairy farms. The HO bull progeny averaged 93% known ancestry background, of which, 76% was HO and 24% was

FR ancestry. The FR steer progeny averaged 94% known ancestry, of which, 77% was FR and 23% was HO ancestry. Similarly this data was calculated using data supplied by the Irish Cattle Breeding Federation (ICBF) on breed fractions. The HO bulls were artificially reared under standardised conditions as described by Fallon (1992).

Animal management

Following purchase, all animals were assembled at the Grange Beef Research Centre, where they remained until slaughter. The HO bull calves were offered concentrates to appetite with straw (and subsequently grass silage) as a source of roughage, from shortly after arrival. The beef breeds (bulls and steers) and the FR steers were vaccinated as a preventative measure for respiratory disease and treated for the control of ecto- and endo-parasites upon arrival at the research centre. They were offered grass silage *ad libitum* and 2 kg of supplementary concentrates over a preliminary period following arrival. While trying to maintain an equal number of progeny per sire, the late-maturing breeds were randomly allocated into either; an "intensive" bull production system where the bulls were slaughtered at 14 to 16 months of age or an "extensive" steer production system where they were slaughtered at approximately 24 months of age. As some animals were already castrated on arrival castration of the remaining animals destined for the steer production system took place at this time. The bull system consisted of 50 late-maturing beef breeds and 22 HO bulls, while the steer system consisted of 56 beef breeds and 23 FR steers.

In the bull system, beef bulls were housed in groups of 7 animals in slatted floor pens and offered feed individually using electrically controlled Calan-Broadbent gates. The HO bulls were tethered individually in slatted stalls. The concentrate allowance was increased gradually for the beef breeds until available *ad libitum* (offered feed was 1.10 × each animal's previous daily intake), while concurrently, the grass silage allowance was reduced to 1 kg of dry matter (DM) per head daily. The HO bulls were already on a concentrate diet *ad libitum* from calfhood. The daily allowance of silage DM provided was also 1 kg per head. The concentrate offered contained 865 kg barley, 70 kg soya bean meal, 50 kg molasses and 15 kg minerals and vitamins per tonne. Refused concentrate and silage feed was discarded once and 3 times weekly, respectively. The animals remained on this high concentrate diet for 133 days from 13 February until slaughter on 26 June 2006. Average age at slaughter for the beef and HO bulls was 470 and 429 days, respectively.

In the steer system, all animals were offered grass silage *ad libitum* plus 2 kg of concentrates (formulation as above) per head per day until 13 March 2006 after which, the daily concentrate offered was decreased to 1 kg per head and subsequently discontinued from 3 April 2006. At the end of the winter housing period steers were turned out to pasture on 18 April where they grazed a predominantly perennial ryegrass (*Lolium perenne*) sward in 2 batches on a paddock system. Each grazing batch was balanced for breed and as far as possible for sire. On 18 October 2006 the steers were re-housed in slatted floor pens with 7 animals per pen and offered grass silage *ad libitum* plus a mineral vitamin supplement through individual electrically controlled Calan-Broadbent gates until 22 December 2006 (59 days). Concentrates (same formulation as above) were then introduced and the allowance was increased gradually until available *ad libitium* in addition to 1 kg of grass silage DM per head daily from January 2007 until slaughter on 13 or 27 April 2007 (mean 87 days). The steers were slaughtered in two groups for logistical reasons and were balanced for breed and as far as possible for sire on each slaughter date.

Animal measurements

All animals were weighed on 5 January 2006. This weight is referred to as 'weight at 10 months of age'. Bulls were subsequently weighed at 28 day intervals from January until slaughter resulting in 7 weight records per bull. Steers were also weighed at 28 day intervals from the initial weight to housing in October 2006 after which, they were weighed every 14 days until slaughter in April 2007 with a total number of 27 weight records per steer. Weighing always occurred prior to the morning feeding or when at pasture prior to movement to the next paddock in the grazing rotation. Live weight gain was calculated by fitting a linear regression through live weights during each of the feeding periods (grazing period, silage period and finishing period) for each animal separately. Within each period, metabolic weight (MWT) was calculated as average live weight$^{0.75}$ for the interval in question. When at pasture, individual daily herbage DM intake was estimated for the steers over a 6 day period in late July and early August, using the n-alkane technique (Mayes et al., 1986) by means of a "controlled release capsule" (Captec (NZ) Ltd., Auckland, New Zealand). Dosing, sampling and processing methodology used was as described by Clarke et al. (2009a).

Both bulls and steers were visually assessed at the start of the experiment (January 2006) for muscularity traits using the Signet (Allen, 1990) and ICBF (ICBF, 2002) scoring procedures. Skeletal scores were also recorded at the same time using the ICBF linear scoring system (ICBF, 2002). These scores were taken to represent live score assessments at 10 months of age. Each animal was also scored for the same traits in the week pre-slaughter. The Signet scoring system assigns visual muscularity scores to each animal at 3 different locations namely roundness of hind-quarter, width of rump and the thickness/width at the loin. The system uses a scale of

1 to 15 where 1 represents low and 15 represents a high degree of muscularity. Each location was given a single score and the 3 scores were averaged to give 1 value for muscularity both at 10 months and pre-slaughter by the same assessor.
Muscularity scores using the ICBF linear scoring system involved visual assessment at 6 different locations namely width at withers, width behind withers, loin development, development of hind-quarter, width at hind-quarter, and development of the inner thigh. The muscularity traits were again scored on a scale of 1 to 15, with 1 for poor and 15 for excellent muscular development. These muscularity scores were then averaged to give one overall muscularity score. The 3 skeletal traits assessed were height at withers, length of back and pelvic length. The skeletal traits were scored on a scale of 1 (short) to 10 (extended). The ICBF muscularity and skeletal scores were all carried out by one person.
At the same time as muscularity scoring, each animal was ultrasonically scanned to obtain *longissimus dorsi* muscle depth and depth of back fat using a dynamic imaging Ultrasound scanner (model - Concept/MCV, with 3.5 MHz head). Muscle depth was measured at the 3rd lumbar vertebra. Four fat depth measurements were taken at the 13th rib and a further three at the 3rd lumbar vertebra. These values were subsequently combined and an average value calculated. Plasma urea, glucose, non-esterified fatty acids (NEFA), cholesterol, beta-hydroxybutyrate (βHB), insulin and insulin-like growth factor (IGF-1) concentrations were measured. The bulls were blood sampled by jugular venipunture on three occasions (1 February, 17 May and 21 June 2006, which corresponded to day -14, 94 and 129 of the concentrate feeding period) when the beef breed bulls were offered a high level of concentrates (day -14) or concentrates *ad libitum* (days 94 and 129). The steers were also blood sampled 3 times during the *ad libitum* concentrate feeding period (1 February, 6 March, and 29 March 2007 which corresponds to days 11, 44 and 67 of the *ad libitum* concentrate feeding period). Blood sampling, processing and laboratory analysis was as described by Clarke et al. (2009b).
Slaughtering of bulls and steers took place in the same commercial meat plant. Post-slaughter, hot carcass weight was recorded and cold carcass weight was taken as 0.98 of hot carcass weight. Kill-out proportion was calculated as cold carcass weight expressed as a proportion of pre-slaughter live weight. Carcass conformation and fat scores were recorded mechanically (Allen and Finnerty, 2000) according to the EU beef carcass classification scheme (Commission of the European Communities, 1982) on a continuous 15 point scale. After 24 h at 4^{o}C, the right side of each carcass was dissected into meat, fat and bone. The side was quartered at the 5th rib into an eight-rib pistola and a fore-quarter. The hind-quarter (pistola) consisted of 13 cuts (silverside, topside, knuckle, rump, cap of rump, tail of rump, fillet, striploin, cube roll, leg, heel, cap of rib, eye of the round). The fore-quarter consisted of 11 cuts (braising muscle, bladesteak, clod, chuck tender, brisket, front shin, flat ribs (rib 1 to 5), plate, chuck, neck, *m. triceps brachii*). All dissectible fat was removed and where applicable bones were also removed and cleaned of all adhering tissue. Each meat cut was weighed and recorded separately. Bone, fat and lean trim (small pieces of meat cut away from bone and fat in the dissection process) were recorded separately for the fore- and hind-quarters. Lean trim was subsequently combined with the meat cuts to give meat yield. The combined meat weight of the fillet, striploin and cube roll was taken to represent the high-value cuts (HVC) in the carcass. This was expressed both as a proportion of the half carcass weight (HVC_C) and as a proportion of the half carcass meat weight (HVC_M). Calculated carcass value, expressed as cent per kg carcass, was the sum of the commercial value of each meat cut (cent/kg multiplied by the corresponding weight of the cut) with a small deduction for bone expressed as a proportion of the half carcass weight. Estimated animal value (€) was calculated as cold carcass weight (kg) multiplied by calculated carcass value (cent/kg) divided by 100.
Live weight and carcass gain per day of age was calculated by dividing live weight at slaughter and carcass weight, respectively, by age in days of each animal at slaughter. Estimated carcass gain (g/day) during the period in which animals were finished on *ad libitum* concentrates was obtained by multiplying average daily live weight gain (g/d) during this period by kill-out proportion (g/kg) at slaughter. Only half of the FR steer carcasses were dissected due to logistical reasons resulting in carcass dissection data from 56 beef breeds and 11 FR in the steer system. All carcasses in the bull system were dissected.
Feed processing and laboratory analysis was as described by Owens et al. (2008). Estimated net energy (NE) content of the various diets was based on the chemical composition and *in vitro* dry matter digestibility (Table 1) according to O'Mara (1996). Feed efficiency was calculated by dividing live weight gain into NE intake (expressed as UFV). Residual feed intake, defined as the difference between an animal's actual feed intake and that predicted on the basis of requirements for maintenance of live weight and average daily gain (Crews, 2005), with negative or lower values more desirable, was calculated. Residual feed intake was assumed to be represented by the residuals from a regression of average daily NE intake on metabolic weight and live-weight gain.

Statistical analysis
The associations between breed group (beef and dairy) and performance were determined using a fixed effect linear model in PROC GLM (SAS, 2008). The data were analysed as two separate data sets, the bull system and

the steer system. Breed was treated as a class variable. Confounding variables adjusted for in the model of analysis where significant (P<0.05) were dam parity and age at the time of the measurement. In the bull system, age was adjusted for within beef and dairy breeds due to the large difference in age (41 days) between the two groups of bulls, but there was no age difference in steers and age was adjusted across breeds. Non-linear associations between age and the dependent variables were also tested for significance in the model. Significance of the effects in the model was based on the F-test with the appropriate degrees of freedom. Grazing batch was included in the model of analysis for data relating to the grazing period.

Preliminary analyses of the blood hormone and metabolite data revealed that some of the parameters were not normally distributed. Therefore, the natural logarithm transformation of insulin, glucose, βHB and IGF-1 were used to normalise the distributions. The associations between breed group (beef and dairy) and systemic hormone and metabolite concentrations were determined using mixed models (SAS, 2008) with animal included as a repeated effect. A compound symmetry covariance structure was assumed among records within animal. The confounding variables, day of blood sampling, dam parity, and age (as above) were adjusted for in the model of analysis where significant (P<0.05).

An additional series of analyses were undertaken using a fixed linear model in PROC GLM (SAS, 2008) to quantify the association between sire breed and performance within the beef progeny. In these analyses bulls and steers were evaluated together in one dataset. Confounding variables adjusted for in the statistical model where significant (P<0.05) were system, dam breed, dam parity and age at the time of the measurement centered within system. The association between sire breed and blood hormone and metabolite concentrations was determined using mixed models (SAS, 2008) with animal included as a repeated effect. Confounding variables adjusted for in the model of analysis where significant (P<0.05) were system, dam breed, dam parity, age at the time of the bleeding centered within system and day of blood sampling**.** Non-linear associations between age and the dependent variables as well as the existence of an interaction between beef breed and production system were also tested for significance in the model. Significance of the effects in the model was based on the F-test with the appropriate degrees of freedom.

3. Results

Comparison of progeny of beef and dairy breeds

Feed intake. The effects of breed group on feed intake and efficiency during the grazing and silage periods in steers are summarised in Table 2. There was no difference in DM or NE intake, or live weight gain between the two breed groups in either feeding period. Mean live weight and metabolic weight was greater (P<0.001) in beef than FR steers during both the grazing and silage periods. When expressed relative to live weight, there was no difference in intake between the two breed groups during the grazing period, but FR had greater intake per unit live weight than beef steers during the silage feeding period.

During the finishing period intake was greater (P<0.05) in beef than HO bulls, whereas there was no difference in either DM or NE intake between beef and FR steers (Table 3). In both systems, mean live weight, metabolic weight, live weight gain, carcass gain was greater (P<0.05), while feed efficiency and RFI was better (P<0.01) in beef than dairy breeds. Dry matter and NE intake expressed relative to live weight was lower (P<0.001) in beef than dairy progeny in both systems.

Live animal measurements. At 10 months of age, across both bulls and steers, beef progeny were heavier (P<0.01) and had higher (P<0.001) Signet and ICBF muscularity scores than dairy progeny (Table 4). There was no difference (P>0.05) between beef and FR steers in the 3 skeletal traits (height at withers, length of back, length of pelvis) however, beef bulls had greater (P<0.05) skeletal scores than HO bulls. Scanned muscle depth was greater (P<0.001) in beef than dairy progeny in both systems, whereas scanned fat depth was greater (P<0.001) in beef bulls than HO bulls with no difference evident between the breed groups in the steer system.

Pre-slaughter, beef progeny were heavier (P<0.05) and had higher (P<0.001) Signet and ICBF muscularity scores than dairy progeny. Height of withers was greater (P<0.01) in beef bulls than HO bulls, whereas the opposite (P<0.05) was true in steers. There was no difference in length of back or length of pelvis between the two breed groups in either the bull or steer system. Scanned muscle depth was greater (P<0.001) in beef than dairy progeny in both systems, but there was no difference in scanned fat depth.

Blood metabolites and hormones. There was no difference between beef and dairy progeny for cholesterol, urea, NEFA, glucose, βHB or IGF-1, but insulin concentrations were lower (P<0.01) in beef than dairy progeny in both systems.

Carcass traits. In both systems, beef progeny had greater (P<0.001) carcass weight, higher kill-out proportion, better carcass conformation scores and greater live weight and carcass gain per day of age than dairy progeny

(Table 5). Both breed groups had similar (P>0.05) carcass fat scores. Carcass meat proportion was greater (P<0.001), whereas carcass fat and bone proportions were lower (P<0.05) in beef than dairy progeny in both systems. The proportion of HVC_C, carcass value and animal value were greater (P<0.001) in beef than dairy progeny in both systems. There was no difference in kidney and channel fat and HVC_M between the two breed groups in the bull system. However, kidney and channel fat was lower (P<0.001) and HVC_M was greater (P<0.05) in beef than in FR steers.

Comparison of progeny of beef sire breeds

Feed intake. During the concentrate feeding period LM had a lower (P<0.05) intake and were lighter than CH and SM with BB being intermediate (Table 6). There was no difference (P>0.05) between the beef breeds in intake expressed relative to live weight, live weight gain, carcass gain, feed efficiency or RFI during the finishing period. There were no significant beef breed × system interactions with the exception of feed efficiency, which manifested itself as BB bulls having greater (P<0.001) feed efficiency than SM bulls, whereas there was no difference between the two breeds as steer progeny.

Live animal measurements. Pre-slaughter, SM had lower Signet muscularity scores (P<0.01) and greater scanned fat depth (P<0.05) than CH and BB, whereas LM were not different from any of the other breeds (Table 7). The ICBF muscularity score was higher (P<0.05) for BB than LM and SM, with CH being intermediate (P>0.05). Height at withers and length of pelvis was greater (P<0.01) for SM than LM, whereas CH and BB were intermediate (P>0.05). Simmental had a greater (P<0.05) length of back than LM and BB but did not differ from CH, which were greater than LM. Length of back did not differ between CH and BB. There was no difference in scanned muscle depth between any of the beef breeds. The ICBF muscularity score and length of back recorded at 10 months had similar trends to those recorded pre-slaughter but there was no other significant breed effect at this time (Table 7). There were no significant beef breed × system interactions.

Blood metabolites and hormones. Cholesterol concentrations were lowest (P<0.05) in SM, but there was no difference between the other beef breeds. Concentrations of IGF-1 were greater (P<0.01) in LM than CH and SM, with BB being intermediate (P>0.05). Concentrations of urea, glucose, NEFA, βHB and insulin did not differ (P>0.05) between the beef breeds. There were no significant beef breed × system interactions.

Carcass traits. Carcass weight was lowest (P<0.05) for LM and kill-out proportion was lowest (P<0.05) for SM compared to the other beef breeds (Table 8). Charolais had a lower (P<0.05) kill-out proportion than BB, whereas LM were intermediate (P>0.05) to CH and BB. Simmental had a poorer (P<0.05) carcass conformation score than CH and BB, with LM being intermediate (P>0.05). Carcass fat score was higher (P<0.06) for SM than CH with BB and LM being intermediate (P>0.05). Carcass gain per day of age was lower for LM than CH and SM, whereas BB were not different (P>0.05) from the other three breeds. Simmental had a lower (P<0.05) carcass meat proportion and carcass value and a higher (P<0.05) carcass fat proportion than the other beef breeds, which did not differ (P>0.05). Carcass bone proportion was higher (P<0.05) for SM than LM and BB, with CH being intermediate (P>0.05). Simmental had lower (P<0.05) HVC_C than CH and LM, with BB being intermediate (P>0.05). There was no difference in HVC_M or animal value among the beef breeds. There were no beef breed × system interactions (P>0.05) with the exception of kill-out proportion, whereby as bulls BB had a greater (P<0.001) kill-out proportion than CH but there was no difference between the two breeds as steers.

Conclusions

For the producer, substantial differences between the beef and dairy breeds exist in terms of feed efficiency, growth, proportion of meat in the carcass and carcass value, all of which favour the beef breeds. The importance of carcass data contributing to breed comparison studies (and also breed improvement programmes) cannot be over-emphasised. This is shown by the improvement obtained for beef over dairy breeds in live weight of 12%, while the improvement of carcass and meat produced of 24% and 33%, respectively. Within the four beef breeds the progeny of Limousin sires had the lowest carcass gain per day of age, while progeny of Simmental sires had the lowest meat yield and carcass value.

Table 1: Chemical composition and *in vitro* dry matter digestibility (s.e in parentheses) of concentrates, grass silage and fresh grass

	System					
	Bulls		Steers			
	Concentrates	Silage[a]	Grass	Silage[b]	Concentrates	Silage[c]
Dry matter (g/kg)	819 (14.2)	242 (65.3)	162 (11.3)	249 (23.9)	799 (17.8)	244 (22.4)
Crude protein (g/kg DM)	124 (10.2)	143 (9.1)	194 (33.9)	144 (6.7)	117 (10.4)	143 (16.4)
Ash (g/kg DM)	38 (5.8)	80 (12.1)	-	72 (7.2)	37 (5.3)	93 (11.7)
Neutral detergent fibre (g/kg DM)	153 (33)	588 (38.9)	-	538 (32.1)	157 (32.9)	538 (32.1)
Acid detergent fibre (g/kg DM)	46 (4.9)	-	-	-	57 (24.7)	-
In vitro dry matter digestibility (g/kg DM)	869 (34.8)	674 (53)	735 (37.9)	745 (21.3)	855 (20.8)	727 (26.8)
pH	-	3.9 (0.54)	-	3.7 (0.08)	-	3.9 (0.31)
Ammonia (mg/100ml)	-	83 (18.1)	-	69 (23.3)	-	80 (26.2)

[a]Silage offered with concentrate to bulls at a rate of 1 kg DM per head daily
[b]Silage offered to steers *ad libitum*
[c]Silage offered with concentrates to steers at a rate of 1 kg DM per head daily

Table 2: Dry matter (DM) and net energy (NE) intakes during the grazing and silage periods of late-maturing beef breeds with Friesian (FR) in the steer system

Trait	Grazing Period[a]				Silage Period[b]			
	Beef	FR	s.e.d.	Significance	Beef	FR	s.e.d.	Significance
Mean age (days)	527	530	9.8	ns	632	638	9.9	ns
DM intake (kg/day)	7.9	7.5	0.35	ns	7.9	7.9	0.20	ns
NE intake (UFV/day)[c]	7.3	6.9	0.32	ns	6.6	6.6	0.17	ns
Live weight (kg)[d]	510	445	10.1	***	576	513	12.2	***
Metabolic weight (kg)[d]	107	97	1.6	***	117	108	1.9	***
DM intake (g/kg live weight)	15.7	16.9	0.68	ns	13.7	15.3	0.27	***
NE intake (UFV*1000/kg live weight)	14.5	15.5	0.63	ns	11.6	12.9	0.23	***
Live weight gain (g/day)	831	796	29.8	ns	487	542	57.2	ns

[a]Grazing period refers to the period from turnout on 18 April 2006 until housing on 18 October 2006
[b]Silage period refers to from housing on 18 October 2006 until 22 December 2006
[c]UFV = Unite Fourragere Viande – Feed unit for meat production
[d]Mean live or metabolic weight during each period

Table 3: Dry matter (DM) and net energy (NE) intakes during the finishing periods of late-maturing beef breeds and Holstein (HO) bulls and Friesian (FR) steers in the bull (133 days duration) and steer (87 days duration) systems

Trait	Bull system				Steer system			
	Beef	HO	s.e.d.	Significance	Beef	FR	s.e.d.	Significance
DM intake (kg/day)	9.3	8.7	0.25	*	11.1	11.1	0.33	ns
NE intake (UFV/day) [a]	10.2	9.4	0.28	**	12.1	12.2	0.37	ns
Live weight (kg) [b]	504	403	12.1	***	695	623	15.9	***
Metabolic weight (kg) [b]	106	90	1.9	***	135	125	2.3	***
DM intake (g/kg live weight)	18.5	21.5	0.4	***	16.0	17.9	0.3	***
NE intake (UFV*1000/kg live weight)	20.2	23.3	0.4	***	17.5	19.6	0.4	***
Live weight gain (g/day)	1587	1158	78.3	***	980	827	65.6	*
Carcass gain (g/day)	932	603	44.8	***	554	415	38.0	***
Feed efficiency (g of live weight gain per UFV intake)	156.3	122.9	6.4	***	80.8	67.7	4.98	**
Residual feed intake (UFV/day)	-0.35	0.59	0.162	***	-0.25	0.82	0.225	***

[a]UFV = Unite Fourragere Viande – Feed unit for meat production
[b]Mean live or metabolic weight during each period

Table 4: Live animal measurements at 10 months and before slaughter of late-maturing beef breeds and Holstein (HO) bulls and Friesian (FR) steers in the bull and steer systems

	Bull system				Steer system			
10 months of age	Beef	HO	s.e.d.	Significance	Beef	FR	s.e.d.	Significance
Mean age (days)	306	264	9.4	***	324	330	13.6	ns
Live-weight (kg)	361	292	11.3	***	367	308	13.5	***
Signet muscular score[a]	7.0	3.1	0.35	***	6.6	4.0	0.39	***
ICBF muscular score[b]	7.1	3.3	0.30	***	7.1	4.0	0.43	***
Height at withers[c]	5.2	4.6	0.20	**	5.2	5.4	0.27	ns
Length of back[c]	5.5	4.6	0.19	***	5.8	5.5	0.28	ns
Length of pelvis[c]	5.1	4.5	0.20	**	5.5	5.1	0.31	ns
Muscle depth, (mm)	62.4	46.4	1.71	***	57.4	43.7	1.79	***
Fat depth, (mm)	1.1	0.5	0.06	***	1.1	1.0	0.06	ns
Slaughter								
Mean age (days)	465	423	9.4	***	781	787	14.3	ns
Live-weight (kg)	614	485	14.6	***	731	672	20.9	**
Signet muscular score[a]	9.2	4.0	0.42	***	8.4	5.1	0.44	***
ICBF muscular score[b]	10.1	4.9	0.29	***	9.3	6.3	0.27	***
Height at withers[c]	6.8	6.2	0.23	**	8.2	9.2	0.34	**
Length of back[c]	7.2	6.8	0.20	P=0.06	8.4	8.2	0.27	ns
Length of pelvis[c]	6.7	6.4	0.22	P=0.09	7.9	8.5	0.32	P=0.06
Muscle depth, (mm)	72.7	55.3	1.61	***	78.6	61.0	1.73	***
Fat depth, (mm)	1.9	1.5	0.28	ns	4.6	4.3	0.53	ns

[a]Signet Scoring Procedure, average of 3 locations, scale 1 (hollow, narrow conformation) to 15 (wide, thick muscled)
[b]Irish Cattle Breeding Federation muscular scoring system, an average of 6 locations, scale 1 (hollow, narrow conformation) to 15 (wide, thick muscled)
[c]Skeletal scores, scale 1(short) to 10 (extended)

Table 5: Carcass weight and carcass composition of late-maturing beef breeds and Holstein (HO) bulls and Friesian (FR) steers in the bull and steer systems

	Bull system				Steer system			
	Beef	HO	s.e.d.	Significance	Beef	FR	s.e.d.	Significance
Age at slaughter (days)	470	428	9.4	***	786	792	14.3	ns
Carcass weight (kg)	353	248	7.9	***	413	351	11.0	***
Kill-out proportion (g/kg)	588	520	5.8	***	566	523	6.9	***
Conformation score[a]	11.1	5.8	0.31	***	9.7	6.1	0.39	***
Fat score[b]	7.8	7.7	0.34	ns	9.4	9.3	0.50	ns
Live weight gain/day of age (g)	1310	1133	31.2	***	929	855	26.8	**
Carcass gain/day of age (g)	754	578	17.0	***	525	447	14.0	***
Kidney and channel fat (kg)	7.1	6.5	1.5	ns	10.5	13.8	0.87	***
Meat (g/kg)	729	674	8.1	***	705	661	10.5	***
Fat (g/kg)	91	107	6.4	*	124	144	9.7	*
Bone (g/kg)	180	219	3.6	***	171	194	3.4	***
HVC_C[c] (g/kg)	74	67	1.3	***	67	59	1.9	***
HVC_M[d] (g/kg)	102	101	1.6	ns	95	90	2.1	*
Carcass value[e] (c/kg)	314	283	3.7	***	297	270	5.9	***
Animal value[f] (€)	1108	703	27.6	***	1224	947	39.2	***

[a]EU Beef Carcass Classification Scheme scale 1 (poorest) to 15 (best).
[b]EU Beef Classification Scheme scale 1 (leanest) to 15 (fattest)
[c]High-value cuts expressed as a proportion of the carcass
[d]High-value cuts expressed as a proportion of the meat (i.e., excluding bone and fat)
[e]The sum of the commercial value of each meat cut with a small deduction for bone and no value on fat expressed as a proportion of the half carcass weight
[f]Carcass value (as above) multiplied by carcass weight.

Table 6: Effect of beef sire breed on intake and measures of efficiency during the finishing period

Trait	CH	LM	SM	BB	Breed
DM intake (kg/day)	10.3(0.15)[a]	9.7(0.23)[b]	10.7(0.24)[a]	10.0(0.35)[ab]	*
NE intake (UFV/day) [a]	11.3(0.17)[a]	10.6(0.26)[b]	11.8(0.27) [a]	11.0(0.4)[ab]	*
Live weight (kg) [b]	609(8.1)[a]	568(12.2)[b]	626(13.1)[a]	594(18.9)[ab]	*
Metabolic weight (kg) [b]	122(1.2)[a]	116(1.8)[b]	125(2.0)[a]	120(2.8)[ab]	**
DM intake (g/kg live weight)	17.2(0.19)	17.3(0.28)	17.3(0.3)	17(0.43)	ns
NE intake (UFV*1000/kg live weight)	18.9(0.21)	18.9(0.31)	19.0(0.34)	18.7(0.48)	ns
Live weight gain (g/day)	1293(40.6)	1238(61.8)	1302(66.5)	1207(94.3)	ns
Carcass gain (g/day)	744(23.3)	722(35.5)	734(38.2)	724(54.1)	ns
Feed efficiency (g of live weight gain per UFV intake)[c]	119(3.2)	119(4.9)	114(5.1)	122(7.5)	ns
Residual feed intake (UFV/day)	-0.27(0.103)	-0.42(0.156)	-0.03(0.169)	-0.31(0.24)	ns

[a]UFV = Unite Fourragere Viande – Feed unit for meat production
[b]Mean live or metabolic weight during each period
[c]Breed × system interaction values: bulls; 163, 150, 150, 166 and steers; 77, 96, 79, 79 for CH, LM, SM and BB, respectively

Table 7: Effect of beef sire breed on live animal measurements at 10 months of age and pre-slaughter

Trait	CH	LM	SM	BB	Breed[a]
10 months of age					
Live-weight (kg)	363(6.4)	347(9.6)	379(10)	375(15.4)	ns
Signet muscular score[b]	6.8(0.18)	6.8(0.27)	6.6(0.28)	7.5(0.43)	ns
ICBF muscular score[c]	7.2(0.16)^{ab}	6.9(0.24)^{a}	6.7(0.25)^{a}	8.0(0.39)^{b}	*
Height at withers[d]	5.1(0.11)	5.1(0.17)	5.5(0.18)	5.1(0.27)	ns
Length of back[d]	5.6(0.12)^{a}	5.5(0.18)^{a}	6.1(0.19)^{b}	5.2(0.29)^{a}	*
Length of pelvis[d]	5.2(0.12)	5.3(0.19)	5.7(0.19)	5.2(0.29)	ns
Muscle depth, (mm)	60.1(0.91)	58(1.42)	60.6(1.44)	61.4(2.2)	ns
Fat depth, (mm)	1.1(0.03)	1.0(0.05)	1.1(0.05)	1.1(0.08)	ns
Slaughter					
Live-weight (kg)	682(8.7)^{a}	630(13.2)^{b}	697(13.7)^{a}	657(21.1)^{ab}	**
Signet muscular score[b]	8.9(0.2)^{a}	8.7(0.31)^{ab}	7.8(0.33)^{b}	9.7(0.49)^{a}	**
ICBF muscular score[c]	9.7(0.12)^{ab}	9.5(0.18)^{a}	9.5(0.19)^{a}	10.2(0.29)^{b}	*
Height at withers[d]	7.6(0.14)^{ab}	7.1(0.21)^{a}	7.9(0.21)^{b}	7.3(0.33)^{ab}	P=0.051
Length of back[d]	7.8(0.11)^{ac}	7.4(0.17)^{b}	8.2(0.18)^{a}	7.4(0.27)^{bc}	*
Length of pelvis[d]	7.3(0.12)^{ab}	7.0(0.19)^{a}	7.7(0.2)^{b}	7.2(0.3)^{ab}	P=0.06
Muscle depth, (mm)	76.0(0.81)	73.8(1.23)	76.9(1.28)	75.6(1.94)	ns
Fat depth, (mm)	2.9(0.19)^{a}	3.4(0.29)^{ab}	4.1(0.3)^{b}	2.9(0.45)^{a}	**

[a]There was no sire breed × system interaction

[b]Signet Scoring Procedure, average of 3 locations, scale 1 (hollow, narrow conformation) to 15 (wide, thick muscled). [c]Irish Cattle Breeding Federation muscular scoring system, an average of 6 locations, scale 1 (hollow, narrow conformation) to 15 (wide, thick muscled). [d]Skeletal scores, scale 1(short) to 10 (extended)

Table 8: Effect of beef sire breed on carcass traits

Trait	CH	LM	SM	BB	Breed
Carcass weight (kg)	388(4.8)^{a}	364(7.2)^{b}	387(7.5)^{a}	391(11.5)^{a}	*
Kill-out proportion (g/kg)[a]	573(2.7)^{a}	582(4.2)^{ac}	562(4.5)^{b}	594(6.6)^{c}	***
Conformation score[b]	10.4(0.16)^{a}	10.3(0.24)^{ab}	9.7(0.26)^{b}	11.1(0.39)^{a}	*
Fat score[c]	8.3(0.19)^{a}	9.0(0.29)^{ab}	9.1(0.31)^{b}	8.4(0.46)^{ab}	P=0.06
Live weight gain/day of age (g)	1143(15.2)^{a}	1048(23.2)^{b}	1158(24.2)^{a}	1080(36.7)^{ab}	**
Carcass gain/day of age (g)	648(8.6)^{a}	608(13.0)^{b}	648(13.5)^{a}	651(20.7)^{ab}	P=0.06
Kidney and channel fat (kg)	8.8(0.71)^{ab}	6.9(1.07)^{a}	11.1(1.12)^{b}	7.6(1.72)^{ab}	P=0.07
Meat (g/kg)	715(4.1)^{a}	724(6.2)^{a}	693(6.7)^{b}	728(10.0)^{a}	**
Fat (g/kg)	108(3.6)^{a}	103(5.5)^{a}	124(5.9)^{b}	102(8.8)^{a}	*
Bone (g/kg)	176(1.5)^{ab}	173(2.3)^{a}	181(2.4)^{b}	170(3.7)^{a}	*
HVC_C[d] (g/kg)	71(0.7)^{a}	71(1.1)^{a}	67(1.2)^{b}	70(1.8)^{ab}	*
HVC_M[e] (g/kg)	99(0.9)	98(1.3)	97(1.4)	96(2.1)	ns
Carcass value[f] (c/kg)	305(2.2)^{a}	308(3.3)^{a}	292(3.5)^{b}	310(5.2)^{a}	**
Animal value[g] (€)	1175(16.7)	1124(25.1)	1121(27.0)	1210(40.7)	ns
Age at slaughter (days)	618(6.1)	632(9.2)	626(9.9)	651(14.8)	ns

[a]Breed × system interaction values; bulls; 577, 593, 575, 617 and steers; 569, 570, 549, 570 for CH, LM, SM and BB, respectively

[b]EU Beef Carcass Classification Scheme scale 1 (poorest) to 15 (best). [c]EU Beef Classification Scheme scale 1 (leanest) to 15 (fattest). [d]High-value cuts expressed as a proportion of the carcass. [e]High-value cuts expressed as a proportion of the meat (i.e., excluding bone and fat). [f]The sum of the commercial value of each meat cut with a small deduction for bone and no value on fat expressed as a proportion of the half carcass weight. [g]Carcass value (as above) multiplied by carcass weight.

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