J. Dairy Sci. 102:10056–10072
https://doi.org/10.3168/jds.2019-16912

A breeding index to rank beef bulls for use on dairy females to maximize profit

D. P. Berry,[1]* P. R. Amer,[2] R. D. Evans,[3] T. Byrne,[2] A. R. Cromie,[3] and F. Hely[2]
[1]Teagasc, Animal and Grassland Research and Innovation Centre, Moorepark, Fermoy P61 P302, Co. Cork, Ireland
[2]AbacuBio Ltd., Dunedin 9016, New Zealand
[3]Irish Cattle Breeding Federation, Highfield House, Shinagh, Bandon P72 X050, Co. Cork, Ireland

ABSTRACT

The desire to increase profit on dairy farms necessitates consideration of the revenue attainable from the sale of surplus calves for meat production. However, the generation of calves that are expected to excel in efficiency of growth and carcass merit must not be achieved to the detriment of the dairy female and her ability to calve and re-establish pregnancy early postcalving without any compromise in milk production. Given the relatively high heritability of many traits associated with calving performance and carcass merit, and the tendency for many of these traits to be moderately to strongly antagonistic, a breeding index that encompasses both calving performance and meat production could be a useful tool to fill the void in supporting decisions on bull selection. The objective of the present study was to derive a dairy–beef index (DBI) framework to rank beef bulls for use on dairy females with the aim of striking a balance between the efficiency of valuable meat growth in the calf and the subsequent performance of the dam. Traits considered for inclusion in this DBI were (1) direct calving difficulty; (2) direct gestation length; (3) calf mortality; (4) feed intake; (5) carcass merit reflected by carcass weight, conformation, and fat and the ability to achieve minimum standards for each; (6) docility; and (7) whether the calf was polled. Each trait was weighted by its respective economic weight, most of which were derived from the analyses of available phenotypic data, supplemented with some assumptions on costs and prices. The genetic merit for a range of performance metrics of 3,835 artificial insemination beef bulls from 14 breeds ranked on this proposed DBI was compared with an index comprising only direct calving difficulty and gestation length (the 2 generally most important characteristics of dairy farmers when selecting beef bulls). Within the Angus breed (i.e., the beef breed most commonly used on dairy females), the correlation between the DBI and the index of genetic merit for direct calving difficulty plus gestation length was 0.74; the mean of the within-breed correlations across all other breeds was 0.87. The ranking of breeds changed considerably when ranked based on the top 20 artificial insemination bulls excelling in the DBI versus excelling in the index of calving difficulty and gestation length. Dairy breeds ranked highest on the index of calving difficulty and gestation length, whereas the Holstein and Friesian breeds were intermediate on the DBI; the Jersey breed was one of the poorest breeds on DBI, superior only to the Charolais breed. The results clearly demonstrate that superior carcass and growth performance can be achieved with the appropriate selection of beef bulls for use on dairy females with only a very modest increase in collateral effect on cow performance (i.e., 2–3% greater dystocia expected and a 6-d-longer gestation length).

Key words: dairy–beef, dystocia, easy calving, carcass

INTRODUCTION

Modern dairy cow breeding goals almost exclusively focus on the efficiency of milk production and functionality, and even when taking beef merit into account (e.g., Ireland, Roche et al., 2018; Scandinavia, Philipsson et al., 1994), the breeding goals remain strongly dominated by milk production and cow functional traits. The gains in milk production efficiency from selecting on such breeding objectives are undisputed (García-Ruiz et al., 2016). Nonetheless, the sale of surplus calves and cull cows can still represent a sizable component (10–20%; van der Werf et al., 1998) of gross income on dairy farms. Until relatively recently, reproductive performance has been deteriorating in many dairy cow populations, forcing almost all dairy females to be inseminated with dairy semen to generate

Received May 5, 2019.
Accepted July 15, 2019.
*Corresponding author: donagh.berry@teagasc.ie

sufficient replacement dairy females. Improving dairy cow reproductive performance in recent decades (Berry et al., 2013) provides an opportunity to use more beef bulls on a greater proportion of dairy females deemed not suitable for the generation of dairy replacements. Therefore, a decision support tool is required to help identify suitable beef bulls for use on dairy females that will maximize the resulting calf sale value with minimal repercussions on the subsequent performance of the dairy female.

Although breeding objectives to rank dairy bulls for use on dairy cows (Veerkamp et al., 2002; Miglior et al., 2005) or to rank beef bulls for use on beef cows (Phocas et al., 1998; Amer et al., 2001; Wolfová et al., 2005) are well documented in the literature, few studies have attempted to develop a ranking tool for beef bulls for use on dairy females. The known association between calving difficulty and both milk production (Dematawewa and Berger, 1997; Berry et al., 2007; Eaglen et al., 2011) and subsequent reproductive performance (Dematawewa and Berger, 1997; Berry et al., 2007; Eaglen et al., 2011) in dairy cows is well established. Calving difficulty in cattle is heritable (Eaglen and Bijma, 2009; Mujibi and Crews, 2009; Crowley et al., 2011), and thus any bull used on dairy cows should ideally be easy calving. The importance of calving date, especially in seasonal calving systems, implies that the bull should also excel in genetic merit for short gestation, which is a highly heritable trait (Mujibi and Crews, 2009).

The objective of the present study was to derive the framework of an index that ranks beef bulls for use on dairy females in the pursuit of maximizing the value of the calf while taking into account the desires of the dairy producer to maximize profit from the lactating female. The index was populated by costs and prices representative of Irish production systems and the expected response to selection compared with an index based solely on calving difficulty and gestation length. A key attribute of the index is the inclusion of nonlinear weightings on traits that facilitate a single index framework suitable for a highly divergent set of sire breeds of interest.

MATERIALS AND METHODS

All cattle data used in the present study were sourced from the Irish Cattle Breeding Federation (http://www.icbf.com) national database.

Framework of the Dairy–Beef Index

The dairy–beef index (**DBI**), developed to identify the most appropriate beef bulls for use on dairy females to create a valuable calf with minimal repercussions on the female, was constructed as

$$\begin{aligned}\mathrm{DBI} = a_1 \times \mathrm{CDE}_1 \times \mathrm{PTA}_1 + a_2 \times \mathrm{CDE}_2 \times \mathrm{PTA}_2 \\ + \ldots + a_n \times \mathrm{CDE}_n \times \mathrm{PTA}_n + \mathrm{CDE}_{n+1} \\ \times \mathrm{f}(\mathrm{PTA}_{n+1}) + \mathrm{CDE}_{n+2} \times \mathrm{f}(\mathrm{PTA}_{n+2}) \\ + \ldots + \mathrm{CDE}_{n+m} \times \mathrm{f}(\mathrm{PTA}_{n+m}),\end{aligned}$$

where a_x refers to the economic value for trait x, CDE_x refers to the cumulative discounted genetic expressions (i.e., frequency and timing of expressions) for trait x, and PTA_x refers to the predicted transmitting ability for trait x. For traits $n + 1$ to m, the value of trait expressions is described through a functional (f) relationship between profit and the level of the PTA of the trait that is nonlinear.

In the present study, the traits of the bull considered for inclusion in the DBI were (1) direct calving difficulty, (2) direct gestation length, (3) calf mortality, (4) calf feed intake, (5) carcass weight, (6) carcass conformation, (7) carcass fat, (8) whether the animal reached a desired carcass specification, (9) calf docility, and (10) whether the calf was polled. Other potential traits that could be included in such an index are discussed later.

National Genetic Evaluations

National cattle genetic evaluations in Ireland are based on a multibreed population and undertaken using the MIX99 software suite (Strandén and Lidauer, 1999). The vast majority of Irish beef cattle are crossbred, and hence all evaluations adjust for the heterosis and recombination loss coefficient of the animal and, where relevant, the dam. The use of phantom groups in the genetic evaluation pedigree accounts for breed differences. Substantial transfer of genetic material exists between Irish dairy and beef herds; herdbook-registered beef bulls are frequently used as natural service sires in dairy herds. Furthermore, some commercial beef dams originate as beef-sired females from dairy herds (Berry et al., 2006). Genetic evaluations for calving and carcass performance traits therefore use both beef and dairy herd data. Further details on the national genetic evaluations are provided in Evans et al. (2007, 2009).

Direct and maternal PTA for calving performance traits are estimated using a recently developed 6 × 6 multitrait evaluation built specifically for the DBI that includes the traits dairy heifer, dairy cow, beef heifer and beef cow calving difficulty, birth size, and birth weight. The PTA for gestation length and mortality at birth are estimated using a separate existing routine 7 ×

7 multitrait evaluation that also includes calving difficulty, birth weight, and additional predictor live weight traits. The PTA for the carcass traits and feed intake are estimated using 3 additional multitrait evaluations that also contain 6 live weight traits, 2 linear-scored composite traits, 3 auction price traits, and cull cow carcass traits as predictor traits. The PTA for weanling docility are estimated using a multitrait evaluation that includes the traits of farmer-scored weanling docility (scale of 1 to 5), weanling docility scored by professional classifiers (scale of 1 to 9), and farmer-scored docility in cows (scale of 1 to 5); all docility measures are subjectively assessed with 1 representing aggressive and a higher number representing more docile. The current national genetic evaluations use 5.5 million calving records, 8.3 million carcass records, and 6,100 feed intake records. Feed intake records all originate from the national bull performance test station (before the year 2012) or the national progeny performance test station (after the year 2012). The protocols, diets, and data-editing procedures are outlined in detail by Crowley et al. (2010).

Frequency and Timing of Trait Expression

Traits differ in their timing and frequency of expressions and such differentials are captured in cumulative discounted genetic expressions (**CDE**), which are subsequently applied to the economic values to ensure commonality in both time and frequency of expression. Berry et al. (2006) described a set of generic equations to track the expression of the genetic superiority of a bull throughout a population embarking on either straight breeding or crossbreeding but also considering possible integration and transfer of germplasm between dairy and beef production systems. The CDE used in the present study were those reported by Berry et al. (2006) from the mating of a sire of breed B (here a beef bull) to a female of breed A (here a dairy female) parameterized with Irish national statistics (case study I as per Berry et al., 2006). In this case, although most of the progeny produced from this mating will be slaughtered as prime animals, some may enter the beef herd, thus also expressing the traits of the sire. The reported CDE were expressed relative to a birth trait for use in the present study. Here it was assumed that 12% of the progeny from the beef × dairy mating enter the beef herd as dams, with half of these becoming self-replacing females and the other half becoming females that produce calves for slaughter. In doing this, the expression of traits in the beef herd is accounted for, although not all traits of interest to beef farmers are embodied within the DBI. The CDE used for the different categories of traits are listed in Table 1.

Economic Values

Calving Assistance. Data were available on the extent of calving assistance required for singleton calves born in Irish dairy herds from the year 2013 on. Only data from the calving months of January through April (predominant calving months in Ireland; Berry et al., 2013) were retained, and calving events within 600 d of the date of data extraction (i.e., March 27, 2018) were not considered further. In total, 2,558,379 calving events from 1,286,214 cows calving in 19,077 dairy herds were available. The extent of calving assistance required at calving is measured subjectively by Irish farmers on a scale of 1 to 4, where 1 = no assistance, 2 = assistance provided with some calving difficulty, 3 = assistance provided with considerable calving difficulty but without veterinary intervention, and 4 = assistance provided with considerable calving difficulty resulting in veterinary intervention (includes caesarean sections as well as veterinary interventions that did not require a caesarean section). For this reason, as described later, category 4 was subdivided into caesarean versus non-caesarean in the present study for the calculation of economic values.

Only herd-years where some variability in calving difficulty scores existed were retained. A total of 2,036,407 calving events from 1,087,448 females in 18,200 dairy herds were available; 24.27% (i.e., 89,096) of the calving events were available on females calving for the first time. Whether the calf died within the first 5 d of life was available for all calving events. The number of days between successive calving events for a given cow was used to calculate calving interval, and only calving interval values between 300 and 600 d were retained. Whether the cow calved again in the next 600 d was used as a measure of survival to the subsequent lactation; the exception was for cows that had their last recorded calving within 600 d of the date of data extraction, which were treated as having unknown survival. Milk yield in the following lactation, in the form of 305-d milk yield, was available for 1,399,094 of the lactations with calving performance information.

Table 1. Cumulative discounted expressions extracted from Berry et al. (2006) for the mating of a beef-breed sire to a dairy-breed dam with 12% of the resulting progeny entering the beef herd to become dams of the next generation

Trait	From Berry et al. (2006)	Expressed relative to birth
Annual	0.24	0.36
Replacement	0.06	0.09
Cull	0.04	0.06
Birth	0.66	1.00
Slaughter	0.41	0.62

Table 2. Contributing factors and assumptions underpinning the economic value of calving difficulty (as recorded by farmers) in primiparous cows

Item	Caesarean (calving score = 4)	Veterinary assistance (calving score = 4)	Severe assistance (calving score = 3)	Slight assistance (calving score = 2)
Stockperson labor (h)	5	3	2	1
Stockperson cost (€/h)	15	15	15	15
Veterinary costs (€)	300	80	0	0
Probability of a dead cow	0.065	0.065	0.025	0.005
Cost of replacement heifer (€)	1,545	1,545	1,545	1,545
Cost of dead cow (€)	1,645	1,645	1,645	1,645
Deterioration in survival to next lactation	0.23	0.23	0.08	0.02
Deterioration in infertility	0.16	0.16	0.06	0.02
Cull cow value (€)	604	604	604	604
Barren cow costs (€)	941	941	941	941
Lost milk (kg)	131.10	131.10	69.96	19.10
Milk price (€)	0.31	0.31	0.31	0.31
Increase in calving interval (each for 3.2 yr)	20.16	20.16	6.891	1.998
Cost of calving interval (€/d)	3.86	3.86	3.86	3.86
Additional number of services	0.2656	0.27	0.1005	0.041
Cost per service (€)	18	18	18	18
Calving cost relative to no assistance (€)	930	680	233	72
Percentage of calvings with 4% difficult	0.55	1.66	1.79	16.35
Percentage of calvings with 5% difficult	0.75	2.09	2.16	18.44
Difference	0.20	0.43	0.37	2.09
Economic effect of 1% change (€/cow)				−7.15

Similarly, the number of inseminations, as defined by Berry et al. (2013), in the lactation immediately following the calving event was also available for 1,298,776 of the calving events. Data on when a cow died on farm were also available.

A series of linear mixed models in ASReml (Gilmour et al., 2009) was used to quantify association between the level of calving assistance with milk yield, cow mortality, calf mortality, cow survival, calving interval, and number of services. This was done separately for primiparous and multiparous cows to estimate the association between calving difficulty score and performance, which could then be used in the derivation of the economic weights. The univariate model fitted was

$$Y_{ijklm} = \text{herd-year}_j + \text{month}_k + \text{parity}_l + \text{cow}_i + \text{e}_{ijklm},$$

where Y_{ijklm} is the performance trait (milk yield, cow mortality, calf mortality, cow survival, calving interval, number of services), herd-year$_j$ is the fixed effects of herd-year of calving, month$_k$ is the fixed effect of month of calving, parity$_l$ is the fixed effects of parity (for the multiparous cow analyses), cow$_i$ is the random effect of cow to account for a permanent environmental effect, and e_{ijklm} is the random residual term. The model solutions for calving difficulty scores of 2, 3, and 4 were generated relative to a score of 1 (i.e., no calving assistance); model solutions for each performance trait are shown in Tables 2 and 3 for primiparous and multiparous cows, respectively. The effect of a delayed calving interval in primiparous cows was assumed to remain throughout their life (i.e., 3.2 more lactations), whereas the effect of a delay in calving in multiparous cows was assumed to last, on average, 1 more lactation. Farm labor was assumed to cost €15/h, with the time per calving event differing by the extent of calving difficulty (Tables 2 and 3). Veterinary costs were based on collated statistics of veterinarian fees by geographical region in Ireland; category 4 calving difficulty scores were stratified into caesarean or not, with the only difference being the associated labor and veterinary costs. The cost of a replacement heifer was assumed to be €1,545 based on output from the Moorepark Dairy Systems model (Shalloo et al., 2004). When an animal died on farm, the cost of the disposal of the dead cow, which is a legal requirement in Ireland, was €100. Milk price was assumed to be 30.5 c/L.

Individual cow carcass value was available on 180,931 dairy cows slaughtered in 23 different abattoirs between 2013 and 2017. All cows were slaughtered directly from the dairy farm and within 300 d of the last calving (i.e., unlikely to have been exposed to a finishing period before slaughter). The mean carcass value of primiparous and multiparous cows was €604 (SE = 1.8) and €674 (SE = 0.64), respectively.

The economic value for calving difficulty was calculated as outlined in detail by Amer et al. (2001) for primiparous and multiparous cows separately. The economic value was defined on an underlying liability scale, and the thresholds imposed on the distribution were such to achieve 4 and 3% of the calving events in primiparous and multiparous cows, respectively, to require considerable assistance (i.e., scores ≥3); these values were the mean incidence of the respective strata in the edited data set. Following the notation of Amer et al. (2001), the average cost of calving in either primiparous or multiparous cows separately was defined as

$$\text{cost} = \sum_{i=1}^{t} p\left(u\right)_i a_i,$$

where $p(u)_i$ is the probability of a normally distributed calving liability lying between the calving score thresholds T_i and T_{i+1} given the population mean (discussed above), and a_i is the calving costs associated with the calving liabilities between the thresholds T_i and T_{i+1}. Because in the present study the model solutions were expressed relative to no requirement for assistance at calving, the cost calculated herein is relative to no calving assistance required. The economic value for primiparous and multiparous cows was then separately derived as the partial derivative of the equation above assuming a 1-percentage-unit change in the calving score ≥3 on the underlying normal scale. A CDE of 1 (i.e., birth trait in Table 1) was associated with the calving ease trait.

A survey of Irish dairy and beef farmers was undertaken in 2015 to explore farmer views and perceptions on the economic and noneconomic consequences of calving difficulty (Martin-Collado et al., 2017). As part of the survey, farmers were asked what the calf value would need to be to tolerate bulls with certain direct calving difficulty PTA. The shape of the tradeoff curve between calf value and calving difficulty level reported by Martin-Collado et al. (2017) was then used to create a nonlinear weighting on calving difficulty for inclusion in a DBI. The nonlinear weighting for calving difficulty is designed to be tangential to the linear calving difficulty weighting at low levels of calving difficulty and then drop away following the shape of the curve from the survey results.

In the linear DBI, the dairy heifer and dairy cow split calving PTA are multiplied by separate economic values and combined with a linear weighting of 10% dairy heifer and 90% dairy cow, based on proportional usage. This weighted combination of dairy heifer and dairy cow was used in the nonlinear calving difficulty function, with the economic weight of €6.91 used for the slope of the nonlinear curve at the population mean. The nonlinear weighting (Figure 1) was parameterized to be equal to the linear weighting at 3% calving difficulty on the combined dairy heifer and dairy cow trait based on the outcomes of the survey undertaken by Martin-Collado et al. (2017).

Calf Mortality. Calf sale prices were available on 99,056 singleton calves born in dairy herds and sold singly at livestock marts between the years 2013 and 2017, inclusive. All calves were sold between 5 and 42 d of age in the first 5 mo of the year; most dairy calves are sold during these months in Ireland (Mc Hugh et

Table 3. Contributing factors and assumptions underpinning the economic value of calving difficulty in multiparous cows

Item	Caesarean (calving score = 4)	Veterinary assistance (calving score = 4)	Severe assistance (calving score = 3)	Slight assistance (calving score = 2)
Stockperson labor (h)	5	3	2	1
Stockperson cost (€/h)	15	15	15	15
Veterinary costs (€)	300	80	0	0
Probability of a dead cow	0.100	0.100	0.044	0.011
Cost of replacement heifer (€)	1,545	1,545	1,545	1,545
Cost of dead cow (€)	1,645	1,645	1,645	1,645
Deterioration in survival to next lactation	0.264	0.264	0.115	0.041
Deterioration in infertility	0.16	0.16	0.07	0.03
Cull cow value (€)	674	674	674	674
Barren cow costs (€)	871	871	871	871
Lost milk (kg)	152.90	152.90	56.35	10.40
Milk price (€)	0.31	0.31	0.31	0.31
Increase in calving interval (for 2 lactations)	15.08	15.08	5.39	2.25
Cost of calving interval (€/d)	3.86	3.86	3.86	3.86
Additional number of services	0.20	0.20	0.10	0.04
Cost per service (€)	17	17	17	17
Calving cost relative to no assistance (€)	849	599	225	81
Percentage of calvings with 3% difficult	0.38	1.23	1.39	13.91
Percentage of calvings with 4% difficult	0.55	1.66	1.79	16.35
Difference	0.17	0.43	0.40	2.44
Economic effect of 1% change (€/cow)				−6.88

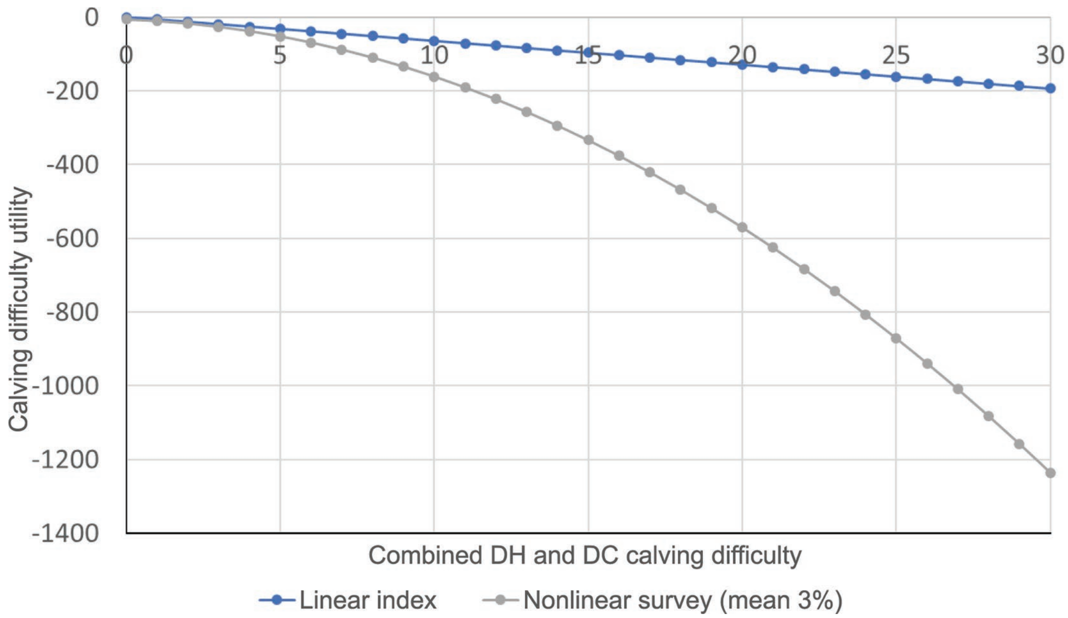

Figure 1. The nonlinear penalty applied to calving difficulty when dairy heifer (DH) calving difficulty and dairy cow (DC) calving difficulty are combined.

al., 2010) to derive the mean calf price at a constant age. A fixed effects linear model was run as

$$Y_{jklm} = \text{herd-year}_j + \text{mart-year}_k + \text{age}_l + e_{jklm},$$

where Y_{jklm} is the calf sale price, herd-year$_j$ is the fixed effects of herd-year of sale, mart-year$_k$ is the fixed effect of mart-year of sale, age$_l$ is the covariate representing age at sale, and e_{jklm} is the random residual term. The least squares means price of a 14-d-old calf was €187.18 (SE = 0.51). The cost of rearing the calf to 14 d of age (i.e., milk replacer, labor, drugs) was assumed to be €50. The cost of disposing of a dead calf, which is a legal requirement in Ireland, and the associated labor, was assumed to be €20 and €15, respectively. Using a CDE of 1 (i.e., a birth trait from Table 1), the economic weight of calf mortality, which included the opportunity cost of the calf (i.e., €187.18), was

$$-[(€187.18 - €50 + €20 + €15)/100] = -€1.72.$$

Gestation Length. The seasonal dairy production systems operated in Ireland rely on cows calving in a concentrated period of the spring immediately before the initiation of grass growth. The seasonality of calving and breeding in Irish dairy cows has been illustrated elsewhere (Berry et al., 2013). Shalloo et al. (2014) stated that a 1-d delay in calving date in Irish dairy herds would cost, on average, €3.86. Using a discount rate of 0.07 (Berry et al., 2006) and assuming that a 1-d delay in calving due to a 1-d-longer gestation length in the current calf affects both the current lactation and just 1 subsequent lactation, then the cost of a 1-d slippage in gestation length due to the direct genetic effect of the bull will be

$$-\{€3.86 + €3.86[1/(1 + 0.07)]\} = -€7.47.$$

A CDE of 1 was used because gestation length is expressed once per birth.

Feed Intake. The economic value for feed intake of the growing animal was that used in the Irish national breeding objective, derived from a bioeconomic model of an Irish beef farm (Crosson et al., 2006). The model is a single-year, static simulation model and provides the capacity to model uncertainty using stochastic variables and running the model for a fixed number of draws using Monte Carlo simulation. The bioeconomic model runs on a monthly time-step and assumes a steady-state system over a calendar year. Animal numbers and the live weight of each animal group (i.e., cows, calves, yearlings, and 2-yr-olds) are specified. Default values for the proportion of grazed grass and grass silage in the animals' diet are specified on a monthly basis. Using the French net energy system (Jarrige, 1989), animal feed requirements are calculated and, based on the feed requirements, grass and silage intake is calculated. Supplemental concentrates are fed where the energy supplied in the forage diet is not sufficient to meet requirements.

The derived economic value for feed intake reflects the dietary proportions and relative feed costs of grazed grass, grass silage, and concentrate ration in the feed budget of growing beef animals. The economic value for feed intake used in the national beef breeding objective is −€49.53. The CDE used in the present study for feed intake was that of a slaughter trait (where the main cost of feed will be realized) plus the replacement trait (which was not included in the expression of the slaughter traits). Therefore, the economic weight for feed intake used in the DBI was

$$-€49.53 \times (0.62 + 0.09) = -€35.27.$$

Carcass Merit. Carcass payment to producers in Ireland (as with most EU countries) is based on carcass weight, carcass conformation, and carcass subcutaneous fat score. A complex price grid stating price per kilogram with incentives for optimum carcass weight ranges was taken from a large Irish processor specializing in the slaughter of dairy-cross beef animals. Although the majority of the price transitions across the grid can be reflected in linear economic values, more severe per-kilogram penalties for very light carcass weight and very poor conformation created the need for additional nonlinear economic value functions for these traits. Here we first define linear economic values for carcass weight, carcass conformation, and carcass fat. We then describe the derivation of additional nonlinear economic value functions for carcass weight and carcass conformation that work additively to the base linear functions.

Carcass price data on a total of 1,149,119 singleton steers born in Irish dairy herds slaughtered between the years 2013 and 2017 inclusive were available. All steers were slaughtered between 20 and 36 mo of age. A fixed-effects linear model with price per kilogram as the dependent variable and just age (in months) at sale as the independent variable was run. The mean price of steers slaughtered at 28 mo of age (i.e., the average of the data set) was €3.91/kg (SE = 0.09), which represents a linear economic value for carcass weight across the price grid. A CDE of 0.62 (Table 1) was applied representing a slaughter trait expression resulting in an economic weight of €2.43.

In Ireland, carcasses are appraised under the EU beef carcass classification system (EUROP) for conformation and subcutaneous fat cover graded using video image analysis (Pabiou et al., 2011b). The 15-point conformation classification system attempts to describe the conformation of the animal based mainly on the round, back, and shoulder. A score of 1 reflects poor conformation, whereas a score of 15 reflects excellent conformation (Englishby et al., 2016). Carcass fat score attempts to describe the fat cover on the outside of the carcass and in the thoracic cavity and is graded as 1 (low fat cover) to 15 (high fat cover). Rather than base the economic values on the current carcass payment system, carcass primal cut data were available from 31,960 animals slaughtered between the years 2013 and 2017 that also had data on their EUROP classification; Judge et al. (2019) described in detail how the data set was generated. For the purpose of the present study, 3 groups of primal cuts were considered as derived by Judge et al. (2019). The groups of cuts were termed frying (i.e., striploin, fillet, rump), roasting (i.e., topside, knuckle, silverside flat, eye of round), and mincing (i.e., bavette, chuck and neck, heel and shank, chuck tender).

For each primal cut separately, only cut weights that had the fat trimmed to the same retailer cut specification and that occurred in high frequency were retained, and both sides of the animal carcass had to have been cut to the same specification for that cut. Data edits that were applied to ensure data integrity are detailed in Judge et al. (2019). Multiple linear regression was used to regress the weight of each trimmed primal cut on each of carcass weight, conformation score, and fat score simultaneously. The regression was undertaken only in steers. The regression coefficients of each cut for conformation were summed up, within group of cuts, to obtain a single regression value for conformation for each of the frying, roasting, and mincing group cuts; the same approach was used for carcass fat. The overall regression coefficient on conformation and fat score for each of the primal group cuts as well as the assumed value to the farmer of each cut group are shown in Table 4; the value of the cut groups was assumed to be €10/kg, €5/kg, and €2/kg for frying, roasting, and mincing cuts, respectively. The CDE applied to the conformation and fat traits was that of a slaughter trait (i.e., 0.62). Hence, the economic weights for conformation and fat score were €10.92 and −€5.12, respectively.

In Ireland, carcasses weighing less than 270 kg or scoring less than an O = (i.e., 5 on the 15-point scale) receive a further penalty over and above the reduction

Table 4. Regression coefficients of the EU beef carcass classification system (EUROP) carcass conformation and fat score on the primal cut groups as well as the value of each cut group to the farmer

Cut	Conformation	Fat	Value (€)
Frying	0.921	−0.270	10
Roasting	1.538	−1.198	5
Mincing	0.340	0.225	2
Economic value	17.579	−8.243	

in carcass value just described; the additional penalty applied to carcasses that failed to reach either threshold was assumed to be 0.18 c/kg. The penalty for lighter carcasses is to reflect the lesser dilution of fixed costs for the abattoir (e.g., boning) per carcass, whereas the penalty on poorer conformation reflects the inability of that carcass to meet the desired specifications prescribed by retailers to the processors. The probability of the progeny of individual bulls not achieving either the carcass weight or the carcass conformation specification was derived using normal distribution theory, based on the bull's PTA and the phenotypic mean of the base population from the genetic evaluation, adjusted to reflect a dairy dam. The base animal in the Irish national genetic evaluations has a phenotypic carcass weight of 325 kg and a mean carcass conformation score of 6; the mean PTA for carcass weight and conformation of dairy females in Ireland is +2.68 kg and −0.43 units, respectively. The raw standard deviations (after variance due to breed effects was removed) for carcass weight and conformation score were 51 kg and 1.6 units, respectively.

The percentage of a bull's progeny expected to not reach the minimum threshold for trait Y was calculated as

$$P_{\mathrm{Y}} = 100 \times \int_{T}^{\infty} N\left(\chi, \mu_{\mathrm{Y}}, \sigma_{\mathrm{Y}}\right) \delta\chi,$$

where T is the minimum threshold for the phenotypic value of trait Y, μ_{Y} is calculated for each bull as a phenotypic mean for trait Y adjusted to the mean of the dairy females plus the bull's PTA, and σ_{Y} is the raw standard deviation of the phenotype after removal of breed effects scaled by a factor of $1-\frac{1}{4}h^2$ to account for the fact that the progeny of the bulls are paternal half-sibs (where h^2 = heritability).

A correlation exists between the probability of failing to achieve the carcass weight threshold and the probability of achieving the conformation threshold; the correlation between achieving the minimum thresholds for carcass weight and conformation in the data set of steers used previously for the estimation of mean carcass price was 0.17. The mean carcass weight of animals that failed to achieve the desired carcass weight specification was 257 kg, whereas the mean carcass weight of cattle that did not reach the conformation threshold was 314 kg. Given that the financial penalty is larger for failing to reach O =, the probability of failing to reach the target carcass weight given a bull had reached the target conformation was derived and used as the new probability. For a given bull, the probability of failing to achieve the carcass weight threshold (i.e., CWT = 0) given that it achieved the conformation threshold (i.e., CONF = 1) was

$$P\left(\mathrm{CWT}=0 \mid \mathrm{CONF}=1\right) = P\left(\mathrm{CONF}=1\right)\left[\frac{P\left(\mathrm{CWT}=\mathrm{fail} \cap \mathrm{CONF}=\mathrm{pass}\right)}{P\left(\mathrm{CWT}=\mathrm{fail}\right)}\right].$$

Given the mean carcass weight of animals that failed to reach either carcass threshold, a financial penalty of €56.52 (i.e., 314-kg carcass weight times a penalty of €0.18/kg) times the probability of it occurring was applied to carcass conformation and a penalty of €46.26 (i.e., 257-kg carcass weight times a penalty of €0.18/kg) times the probability of it occurring was applied to the carcass weight specification. These nonlinear economic value functions for carcass weight and carcass conformation were applied in addition to the linear economic values for carcass weight and conformation previously discussed.

Polledness. Some breeds of cattle do not have horns, whereas variability exists in the incidence of horns in other breeds. In most cattle production systems in the developed world, horns are removed, generally relatively early in life, and this incurs a cost. A 50-mL bottle of anesthetic was assumed to cost, on average, €37.5, and it was assumed to contain 12 doses per bottle (assuming 4 mL/calf). Only 75% of calves receive an anesthetic, as it is a requirement to use anesthetic only when the calf is disbudded after 3 wk of age. The anesthetic cost per calf was therefore

$$0.75(37.5/12) = €2.34.$$

It was assumed that, including baling time, anesthetic administration, and the disbudding procedure, the cost was €2.50/calf based on the assumption that the labor requirement per animal is 10 min at a rate of €15/h. Assuming that the cost of a gas-powered disbudder is €75 and that it depreciates at a rate of 15%/yr to a final value of €5, then the depreciation cost of the disbudder is €10.50/yr. Using the same method to cost the calf-restraining crate, valued at an average of €532 but lasting 20 yr with a depreciation rate of 5%/yr and returning a final value of €50, results in a yearly depreciation cost of €24.10. The total depreciation cost per year for the 2 pieces of equipment was therefore €34.60. Depreciation costs were included here because they would be realized by the farmer, whereas the depreciation in other fixed assets (e.g., feed intake equipment) would be incurred by the national breeding program. Assuming a herd of 70 dairy calves born, the total depreciation cost was €0.49/calf. Hence, the total cost of disbudding was €2.34 + €2.50 + €0.49 = €5.33. Using a birth CDE (i.e., 1), the economic weight for polledness is €5.33.

Docility. An economic value on docility should take into account the additional time costs associated with poorly docile animals as well as the risk of human injury or death associated with animal attacks. An Irish survey by McNamara et al. (2007) estimated that 1,731 accidents occurred on farms in 2005, of which 65.3% were the result of livestock incidents. Of these livestock incidents, 63.6% occurred on beef farms, accounting for 720 nonfatal accidents. Assuming that 85% (the same proportion as that reported to cause deaths from attacks rather than true accidental incidents) of nonfatal accidents are the result of temperamental animals, then 612 nonfatal injuries per year occur as a result of temperamental animals. Of the 612 accidents reported by McNamara et al. (2007), the proportion that resulted in 0, 1 to 9, 10 to 19, 20 to 99, and ≥100 d off work was 0.187, 0.196, 0.222, 0.076, and 0.319, respectively. The proportion of the 612 accidents that needed only first aid was 0.187, the proportion that needed the expertise of a doctor was 0.248, and the proportion that required a hospital visit was 0.565. Taking the midpoint for each of the categories of work days lost (maximized at 100 d), the weighted average number of days off work as a result of an injury caused by livestock is 40.5 d. By applying the labor cost (€15/h) to 40.5 d at 8 h/d, the average time cost associated with an accident is €4,860. The cost of first aid, including treatment time, materials, and medicine, was assumed to be €50, the cost of doctor treatment was assumed to be €100, and the cost of follow-up treatments (e.g., physiotherapy) and medicine was assumed to be €350 (i.e., €500 in total). A hospital treatment (i.e., time in hospital, surgery, and follow-up) was assumed to cost €2,000. Therefore, the weighted average treatment cost of a farm injury resulting from cattle is €1,263, with the total cost of an on-farm injury being €6,123 (time off work plus treatment costs).

The cost of a farm fatality was assumed to be between £1.5 and 2.0 million (Cockerill, 2006, Queens University of Belfast); assuming an exchange rate of £1.75 million at £1 = €1.14 (as of Jan. 17, 2019) and taking the mid-point of this range, this coverts to €2 million. There were 27 deaths in Ireland between 1996 and 2007 as a result of cattle livestock incidents (HSA, 2019), resulting in an average of 2.25 annually. Of these, 85% were attacks by bulls, cows, and weanlings (HSA, 2019), with the remainder being true accidental incidents (e.g., crushed, trampled, slipped over). Thus, 15% of all incidents causing death were removed from those caused by temperamental animals. The average number of pure temperamental attacks causing death by cattle is therefore 1.92/yr. The weighted average cost of injury or death was then calculated as

$$(612 \times €6{,}123 + 1.92 \times €2{,}000{,}000)/$$
$$(612 + 1.92) = €12{,}343.$$

To convert the calculated average cost per injury or death to a cost per change in docility score, it was assumed that (1) there is a reduction in risk of temperamental animals by 15% for a 1-unit increase in average docility score for a group of animals, (2) 1 temperamental animal increases labor requirements by 3 h/yr per animal over the lifetime of a slaughtered animal or replacement heifer until first calving, (3) 1 temperamental animal increases the likelihood of injury or death by 0.005 (0.5%), and (4) cost of labor was €15/h. Therefore, the economic value per unit change in docility PTA was calculated as

$$\text{(risk of temperamental animal} \times \text{number}$$
$$\text{of additional hours of labor} \times \text{hourly labor cost)}$$
$$+ \text{(risk of temperamental animals} \times \text{likelihood}$$
$$\text{of injury or death} \times \text{cost of injury or death).}$$

In the present study, this was

$$(0.15 \times 3 \times €15)$$
$$+ (0.15 \times 0.005 \times €12{,}343) = €16.01.$$

The discounted genetic expressions of a replacement and slaughter trait were 0.09 and 0.62, respectively (Table 1). Hence, the economic weight was €16.01 × (0.09 + 0.62) = €11.40.

Mean Genetic Merit of High-DBI Sires Versus Current Selection Practices

The mean genetic merit for a range of different traits of the top 25 AI bulls ranking highly on the new DBI was compared with the top 25 AI bulls ranking highly on a combination of only direct calving difficulty and gestation length; the latter index is hereafter referred to as the status quo index. The economic values for direct calving difficulty and gestation length in the status quo index were those from the DBI. Only AI beef bulls with a reliability of >50% for all traits (with the exception of docility and feed intake, for which a minimum reliability threshold of 30% was imposed) were considered in this analysis; information on a total of 3,835 bulls was available. The number of bulls per breed is shown in Table 5.

Table 5. By breed, the number of AI bulls and the mean proportion (Prop) of their progeny expected to fail to reach the minimum threshold for carcass conformation or carcass weight as well as mean statistics for the top 20 bulls per breed ranked on the dairy–beef index (DBI) or only on genetic merit for calving difficulty and gestation length (status quo)

Breed[1]	No.	Prop not reaching conformation threshold	Prop not reaching weight threshold	DBI		Status quo	
				Prop not reaching conformation threshold	Prop not reaching weight threshold	Prop not reaching conformation threshold	Prop not reaching weight threshold
AA	206	0.20	0.08	0.17	0.06	0.19	0.10
AU	20	0.05	0.05				
BA	34	0.03	0.03	0.03	0.03	0.03	0.03
BB	168	0.01	0.03	0.02	0.04	0.02	0.05
CH	272	0.05	0.02	0.06	0.03	0.07	0.04
FR	334	0.43	0.13	0.38	0.11	0.42	0.14
HE	147	0.23	0.08	0.22	0.07	0.24	0.10
HO	1,935	0.56	0.11	0.50	0.09	0.56	0.13
JE	113	0.62	0.25	0.57	0.20	0.60	0.23
LM	357	0.04	0.04	0.02	0.03	0.05	0.05
PT	20	0.03	0.03				
SA	39	0.12	0.05	0.11	0.04	0.13	0.05
SH	43	0.22	0.07	0.19	0.06	0.24	0.09
SI	147	0.12	0.04	0.15	0.04	0.19	0.05

[1]AA = Angus, AU = Aubrac, BA = Blonde d'Aquitaine, BB = Belgian Blue, CH = Charolais, FR = Friesian, HE = Hereford, HO = Holstein, JE = Jersey, LM = Limousin, PT = Parthenaise, SA = Salers, SH = Shorthorn, SI = Simmental.

RESULTS

Table 6 summarizes the economic weights of the different traits in the DBI. The greater economic consequence of a difficult calving in primiparous cows (Table 2) than in multiparous cows (Table 3) was largely attributable to the effect of a delay in calving date lasting for an extra lactation in primiparous cows coupled with the association between severe calving difficulty and calving interval being 5 d longer in primiparous cows relative to multiparous cows. Furthermore, the genetic standard deviation for calving difficulty on a 1-to-4 scale in heifers and cows was 0.22 and 0.11 units, respectively, implying an even greater relative emphasis on calving difficulty in heifers.

The correlations between the PTA of individual traits from 206 Angus AI bulls (i.e., beef breed most frequently used on Irish dairy females) and the DBI are shown in Figure 2. The correlations among the PTA of the component traits themselves for the 206 Angus sires are shown in Supplemental Table S1 (https://doi.org/10.3168/jds.2019-16912). Docility and feed intake were both weakly correlated ($r \leq 0.08$) with the overall DBI, whereas the mean (minimum, maximum) of the correlations between the other traits and the DBI was 0.39 (0.24, 0.62). The correlation in Angus bulls between the DBI and the status quo index (i.e., calving difficulty and gestation length) was 0.74; the mean of the within-breed correlations between the DBI and the status quo index in the other breeds was 0.87, varying from 0.57 in Shorthorns to 0.99 in Charolais. The within-breed genetic standard deviation of the DBI averaged across all breeds was €84. Of the 9 breeds with at least 100 high-reliability AI bulls, the standard deviation in DBI (based on PTA) varied from €24 (Friesian) to €121 (Charolais).

Failure to Reach the Carcass Weight and Conformation Specification

The proportion of progeny from high-reliability AI bulls expected to not achieve the carcass weight and conformation minima thresholds, averaged per breed, is shown in Table 5; also included is the mean proportion per breed as well as for only the top 20 high-reliability AI bulls per breed ranked on either the DBI or the status quo index. The Holstein, Friesian, and Jersey dairy breeds were always the poorest when it came to reaching the minimum thresholds no matter whether it was across all AI sires or just the top 20 AI sires ranked on either DBI or the status quo index. The continental-type breeds (i.e., Aubrac, Belgian Blue, Blonde d'Aquitaine, Charolais, Limousin, Piedmontese, Simmental) were, on average, the best for achieving the

Table 6. Genetic SD, economic value and weight, and cumulative discounted genetic expression (CDE) for the traits included in the dairy–beef index

Trait	Genetic SD	Economic value	CDE	Economic weight
Calving difficulty (multiparous)	0.22	−6.88	1.00	−6.88
Calving difficulty (primiparous)	0.11	−7.15	1.00	−7.15
Calf mortality	0.57	−1.72	1.00	−1.72
Gestation length	1.47	−7.47	1.00	−7.47
Feed intake	0.26	−49.53	0.71	−35.27
Carcass weight	8.37	3.91	0.62	2.42
Carcass conformation	0.20	17.58	0.62	10.90
Carcass fat	0.23	−8.24	0.62	−5.11
Failure to achieve conformation specification		−56.52	0.62	−35.04
Failure to achieve carcass weight specification		−46.26	0.62	−28.68
Docility	0.07	−16.01	0.71	−11.40
Polledness		5.33	1.00	5.33

specifications, with the traditional British breeds (i.e., Angus, Hereford, Shorthorn) being intermediate. When the top 20 AI bulls per breed were chosen based on DBI as opposed to the status quo, the carcass merit of the progeny always improved, with up to 6 percentage points less failing to reach the carcass specifications. The Aubrac and Piedmontese breeds had only 20 bulls each, so no difference existed between the indexes. When comparing the top 20 bulls ranked on DBI versus on the status quo index, the proportion of progeny expected to reach the threshold for carcass conformation improved by 0.02 on average; the greatest improvement was in the Holstein breed, with a 0.06-unit improvement. The corresponding value for carcass weight was a mean improvement of 0.02, with the greatest improvement in any breed being a 0.04-unit improvement in the Holstein.

Breed Differences in the DBI

The mean index values (i.e., status quo and DBI) and mean PTA of the top 20 AI bulls ranked within breed on the status quo index or the DBI are shown in Tables 7 and 8, respectively. If ranked on the status quo index, the top 20 Holstein bulls, on average, outperformed the mean of the top 20 AI bulls of all other breeds, with the

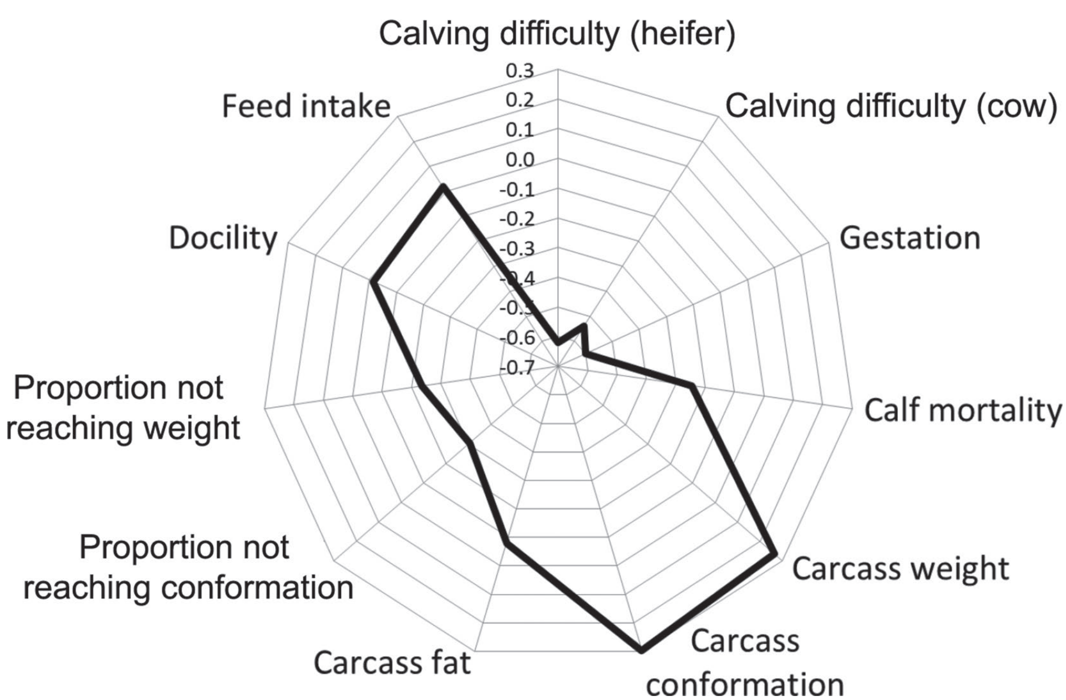

Figure 2. Correlations among the predicted transmitting abilities of the component traits and the dairy beef index among 206 Angus AI bulls.

dairy-breed bulls outperforming the traditional beef-breed bulls, who in turn outperformed the continental beef breeds. Although the mean PTA for calving difficulty in the Jersey breed was superior to that of the Holstein breed, the shorter mean gestation length of the top 20 Holstein AI bulls contributed to the Holstein breed ranking the highest on the status quo index.

The top-ranking breed on the DBI was the Salers breed, attributable to their good characteristics of relatively easy calving (especially on cows) and good carcass merit, albeit with relatively long gestation length. The Charolais breed was, on average, the worst on DBI, owing predominantly to their very difficult calving statistics; 12.49% of the calvings of these top 20 Charolais bulls on heifers were expected to result in a difficult calving (i.e., score of 3 or 4 on the national 1-to-4 scoring system).

Top 25 AI Bulls Ranked on the Status Quo or the DBI

Table 9 summarizes the mean genetic merit of the top 25 bulls (irrespective of breed) ranked on either the DBI or the status quo index. Based on the PTA of the top 25 bulls ranked on either index, there was an expectation that heifers mated to the top 25 bulls on DBI would experience 3 percentage units more calving difficulty, on average, relative to heifers mated to the top 25 bulls ranked on the status quo index; the corresponding value in cows was 2 percentage units more calving difficulty. The gestation length of the higher DBI bulls was, on average, 6 d longer compared with the bulls excelling on the status quo index. However, the progeny of bulls excelling in DBI would be expected to have, on average, a 32-kg heavier carcass and a 2.64-unit greater conformation score on a scale of 1 to 15. Moreover, 55% of the progeny of the top bulls on the status quo index were expected to fail to reach the minimum conformation score, but this reduced to just 5% when ranked on the DBI; the corresponding values for failing to reach the minimum carcass weight were 14 and 4%. All 25 bulls ranked high on the status quo index were Holstein (n = 21), Friesian (n = 2), or Jersey (n = 2); of the 25 bulls ranked on DBI, 10 were Aubrac, 6 were Salers, 3 were Limousin, 3 were Belgian Blue, 1 was Angus, 1 was Blonde d'Aquitaine, and 1 was Piedmontese.

DISCUSSION

Although dairy cow breeders and producers alike have placed considerable emphasis on improving milk quality (i.e., milk fat and protein concentration), less emphasis has been placed on the quality of the beef carcass in the form of surplus calves. This is not surprising

Table 7. Mean values of genetic merit for the dairy–beef index (DBI), an index of direct calving difficulty plus gestation length (status quo), and the component traits of the DBI for the top 20 AI bulls per breed and ranked on the status quo and expressed, within trait, relative to the Holstein breed

Breed[1]	DBI (€)	Status quo (€)	Calving difficulty (% of heifers)	Calving difficulty (% of cows)	Gestation (d)	Calf mortality (%)	Carcass weight (kg)	Carcass conformation (units)	Carcass fat (units)	Docility (units)	Feed intake (kg of DM)
JE	−52	−8	−1.25	−0.34	1.49	0.74	−16.70	−0.14	0.04	−0.05	−0.09
FR	−2	−8	0.44	0.19	0.84	−0.09	−2.00	0.49	0.13	−0.04	−0.08
AA	20	−23	0.58	−0.28	3.26	−0.32	8.90	1.46	0.83	−0.15	0.10
SA	45	−56	2.75	0.68	6.29	−0.36	23.80	1.84	0.03	−0.21	−0.28
HE	−27	−64	4.44	1.43	5.83	−0.05	7.95	1.23	1.08	−0.03	0.01
SH	−33	−80	5.56	2.44	5.93	0.03	12.20	1.25	0.88	−0.32	−0.05
AU	−33	−80	5.56	2.44	5.93	0.03	12.20	1.25	0.88	−0.01	0.08
LM	−10	−81	4.49	2.35	6.35	0.33	25.80	2.57	0.05	−0.14	−0.43
SI	19	−86	4.66	2.47	5.49	0.16	16.13	1.72	0.12	−0.09	−0.20
BB	−46	−102	5.44	2.58	8.55	−0.06	22.25	2.58	0.02	−0.18	−0.64
PT	16	−118	6.66	3.87	7.33	0.19	22.35	1.53	0.15	−0.04	0.31
BA	7	−127	6.32	5.00	5.32	0.33	25.55	3.18	−0.62	0.05	−0.70
CH	−17	−140	8.63	4.39	7.99	0.94	33.10	2.91	−0.50	−0.18	−0.47

[1]JE = Jersey, FR = Friesian, AA = Angus, SA = Salers, HE = Hereford, SH = Shorthorn, AU = Aubrac, LM = Limousin, SI = Simmental, BB = Belgian Blue, PT = Parthenaise, BA = Blonde d'Aquitaine, CH = Charolais.

Table 8. Mean values of genetic merit for the dairy–beef index (DBI), an index of direct calving difficulty plus gestation length (status quo), and the component traits of the DBI for the top 20 AI bulls per breed and ranked on the DBI and expressed, within trait, relative to the Holstein breed

Breed[1]	DBI (€)	Status quo (€)	Calving difficulty (% of heifers)	Calving difficulty (% of cows)	Gestation (d)	Calf mortality (%)	Carcass weight (kg)	Carcass conformation (units)	Carcass fat (units)	Docility (units)	Feed intake (kg of DM)
SA	34	−52	2.55	0.68	5.67	−0.15	17.55	1.75	−0.07	−0.24	−0.36
AU	23	−74	3.86	2.21	5.54	0.51	16.80	2.35	0.02	−0.15	−0.50
LM	19	−111	5.96	3.29	7.75	0.21	24.40	2.91	−0.22	−0.19	−0.66
AA	18	−24	1.60	0.20	2.67	0.20	10.65	1.35	0.58	−0.10	0.23
BB	5	−126	6.14	5.12	4.31	0.50	20.70	3.11	−0.64	0.05	−0.76
FR	−10	−9	0.71	0.37	0.64	−0.06	−4.95	0.43	0.07	−0.06	−0.11
PT	−10	−132	8.00	4.25	7.19	1.13	24.10	2.69	−0.53	−0.19	−0.53
HE	−32	−66	5.25	1.86	4.79	0.16	7.45	1.08	0.83	−0.03	0.01
BA	−33	−158	7.72	4.85	9.18	0.71	25.00	2.64	−0.61	−0.18	−0.55
SH	−40	−82	5.84	2.59	5.54	0.43	10.35	1.29	0.75	−0.01	0.08
SI	−57	−122	7.14	4.22	6.31	0.32	18.65	1.59	0.08	−0.04	0.25
JE	−63	−4	−1.23	−0.29	0.97	0.75	−22.45	−0.27	0.03	−0.06	−0.14
CH	−117	−224	12.49	7.47	6.67	0.26	25.60	2.26	0.02	−0.10	−0.17

[1]SA = Salers, AU = Aubrac, LM = Limousin, AA = Angus, BB = Belgian Blue, FR = Friesian, PT = Parthenaise, HE = Hereford, BA = Blonde d'Aquitaine, SH = Shorthorn, SI = Simmental, JE = Jersey, CH = Charolais.

Table 9. Mean (SD in parentheses) values of genetic merit for the dairy–beef index (DBI), an index of direct calving difficulty plus gestation length (status quo), and the component traits of the DBI for the top 25 AI bulls (irrespective of breed) ranked on either the DBI or the status quo index

Index	DBI (€)	Status quo (€)	Calving difficulty (% of heifers)	Calving difficulty (% of cows)	Gestation (d)	Calf mortality (%)	Carcass weight (kg)	Carcass conformation (units)	Carcass fat (units)	Prop[1] not reaching conformation threshold	Prop not reaching weight threshold	Docility (units)	Feed intake (kg of DM)
DBI	40.26 (9.53)	−50.11 (26.6)	6.96 (1.93)	3.72 (1.42)	0.46 (1.63)	−0.15 (0.56)	23.24 (6.45)	1.88 (0.56)	−0.33 (0.36)	0.05 (0.04)	0.04 (0.01)	0.01 (0.12)	−0.39 (0.33)
Status quo	−26.59 (21.33)	22.65 (3.27)	3.78 (0.89)	1.73 (0.27)	−5.52 (0.53)	−0.26 (0.55)	−8.88 (8.57)	−0.76 (0.21)	−0.18 (0.18)	0.55 (0.06)	0.14 (0.05)	0.12 (0.05)	0.03 (0.09)

[1]Prop = proportion.

given the relatively low contribution of beef sales to the gross income of dairy farms. Nonetheless, potential quotas on dairy cow numbers in some countries as a tool to mitigate deterioration in environmental metrics, coupled with growing angst among consumers about the production systems of these apparently lower quality beef by-products from the dairy herd, warrant examination of tools to improve the beef merit of surplus calves from the dairy herd. Improvements in dairy cow fertility (Berry and Evans, 2014) owing to the broadening of breeding objectives to include measures of reproductive performance (Miglior et al., 2005), coupled with the ever-increasing interest in sexed semen (De Vries et al., 2008), are powerful drivers for the use of more beef bulls on dairy females. Stabilization of currently expanding dairy cow populations in some countries will contribute to a further increase in the number of calves born from beef bulls on dairy females. However, any tool used to identify beef bulls for use on dairy females must be cognizant of the demands of both the dairy producer (i.e., easy calving with short gestation length) and the beef sector (i.e., efficient growth of a good-quality carcass). The DBI proposed in the present study attempts to do just that. Although the economic weights placed on the component traits are from a given moment in time and could change with prices and costs of production, sensitivity analyses revealed that the ranking of bulls was robust to the assumptions. If, for example, the economic weight on any of the DBI component traits was increased by 20%, the rank correlation among the Angus bulls was always ≥0.98; the ranking was most sensitive to the economic value on both calving difficulty and carcass weight.

Achieving Genetic Gain

The DBI as proposed in the present study is populated with moderately to highly heritable traits, many of which are expressed by, and therefore can be recorded on, young bull selection candidates themselves. This is in contrast to many dairy cow traits that are sex linked, expressed relatively late in the life of daughters, and frequently of low heritability (e.g., fertility, survival, and health traits). In the absence of genomic evaluations, young bulls (both dairy and beef breeds) can be assessed for DBI at a substantially younger age than dairy bulls can be assessed for a milk production index; although this differential is now shorter with genomic evaluations, achieving high reliability still requires phenotypic data. Although there is potential also to design progeny testing or genomic selection strategies, low risk associated with calving difficulty genetic evaluations (i.e., high-reliability evaluation) is paramount, especially when beef bulls are intended for mating to heifers. Therefore, until such time that very high accuracy of selection for calving difficulty can be achieved with genomic evaluations, progeny testing for calving difficulty will remain a key strategy for the identification of high-DBI bulls from beef breeds. New breeding strategies incorporating genomic selection and improved recording of calving difficulty in beef herds will be required to enhance the accuracy of DBI predictions of young beef bulls destined for use in dairy herds.

Of particular importance in any good breeding program is the ability to identify genetically elite animals that excel in antagonistically correlated traits. An example of such antagonistically correlated traits in the DBI is calving difficulty and carcass merit; the correlations between the PTA for calving difficulty in cows and both carcass weight and conformation in the Angus AI sires were 0.54 and 0.10, respectively. Breeding programs for DBI should therefore aim to especially identify bulls with good genetic merit for both calving difficulty and carcass weight; this is possible despite the antagonistic correlation of 0.54 between both traits. From a review of up to 8 studies, Berry and Evans (2014) reported a mean genetic correlation between each of milk yield, fat yield, and protein yield and calving interval of between 0.46 and 0.50; despite this, year-on-year genetic progress in both milk production and calving interval simultaneously has been achieved in the past 2 decades (Berry, 2018). Therefore, although the genetic merit for direct calving difficulty of the high-DBI bulls was inferior to that of the bulls excelling in the status quo index (Table 9), the pool of AI bulls used in the present had not been subjected to selection on DBI. In fact, most of the beef bulls have actually been selected for use in beef cows, where the aversion to assistance at calving is generally less (Martin-Collado et al., 2017), with the anticipation that the animal will command a greater price because of its superior carcass merit. Hence, within a relatively short time, it should be possible to reduce the calving difficulty of available AI beef bulls without necessarily introducing a compromise in carcass merit. Actually, such a breeding program would closely mirror terminal sire breeding programs for pigs and poultry. In this instance, a line of beef cattle would be bred solely for use as terminal sires in the dairy herd. In fact, the use of crossbred bulls on dairy females may be a sensible option exploiting the benefits of complementarity between an easy calving breed (with possibly poorer carcass merit) and a breed excelling in carcass merit (but, on average, more difficult calving).

It is also likely that some of the females from such a mating between a high-DBI bull and a dairy female may be suitable replacement females for the beef herd. These females would receive good terminal characteristics from the high-DBI bull coupled with good maternal characteristics (i.e., milk yield and fertility) from the dairy cow. The excellent maternal characteristics of dairy × beef cows have been demonstrated previously. For example, based on a controlled study in Ireland, McCabe et al. (2019) reported that calves weaned from dairy × beef cows were 18.49 kg heavier at weaning, reached slaughter 12.8 d younger, and had a carcass that was 7.99 kg heavier compared with the progeny of beef cows. Furthermore, the dairy × beef cows had a shorter calving interval than their beef cow counterparts, but the odds of the dairy × beef cows surviving to the next lactation were lower. The correlation between the DBI and the Irish national replacement index in the 206 Angus AI bulls was 0.38, implying that superior-DBI female calves should, on average, be relatively superior on the replacement index, but selecting solely for replacement index is a relatively inefficient way of improving the suitability of beef bulls for mating to dairy cows. Also of note was the correlation of 0.64 between the DBI and the Irish national beef terminal index in the 206 Angus AI bulls; although positive, the lack of unity correlation implies that differences do exist in beef bulls for use as terminal sires in dairy cows and beef bulls used as terminal sires in beef cows. The fact that the correlation was less than 0.80 suggests that a separate breeding program is probably justified, in the Angus breed at least, to achieve genetic gain in DBI versus the terminal index (Robertson, 1959), although a thorough business case for separate breeding schemes would need to be developed.

The chances of a separate breeding program being created in Ireland and elsewhere is strong in light of these relatively weak correlations between the DBI and both beef national indexes. Breeds already operate separate terminal and replacement female selection lines, and thus another selection line of cattle for use on dairy females would not be overly taxing. This is especially true given the high level of genomic screening of young calves, enabling elite animals suitable for different breeding systems to be identified and further tested. Given the expansion in many dairy herds globally, coupled with both the improving reproductive performance and uptake of sexed semen, it seems as though the dairy female population is a good potential source for expanding sales. This expansion, however, is crucially dependent on having the correct product for the dairy producer. Thus, the onus is on the beef seedstock breeders to embrace this new market opportunity and breed the most appropriate animals for mating with dairy females.

Traits for Consideration in Future Iterations of the DBI

Traits considered in a breeding objective should be important and heritable and ideally should be measureable on a large population of individuals, preferably at a low cost, or genetically correlated with such traits (Berry et al., 2017a). Many such traits exist but were not considered within the framework proposed here due to a lack of genetic evaluations for these traits in Ireland. Age at slaughter affects the fixed and variable costs of production on farm and is known to be heritable (Berry et al., 2017b). Because there is a legal requirement to record all dates of birth and death (i.e., slaughter), the resources required to generate genetic evaluations for age at slaughter are minimal. Although more expensive to measure, heritable genetic variability in meat quality traits is also known to exist in cattle (for a review, see Berry et al., 2017a). With growing interest in the sustainability of ruminant production systems and their hoofprint on the environment, the carbon cost of each animal, be it through methane measurement or otherwise, should be considered in all breeding indexes, let alone the DBI. Although the cost of measuring individual animal methane emissions in cattle is large, genetic variability is known to exist (Hayes et al., 2016). Therefore, there certainly is merit in considering methane as a goal trait in future iterations of the DBI, although genetic merit for methane emissions would most likely be predicted using selection index theory of predictor traits. Other traits potentially for consideration in later iterations of the DBI that are known to be important and where genetic variability has been demonstrated include calf vigor (e.g., subjectively scored; Riley et al., 2004) and calf health (e.g., scour, umbilical infection; Vinet et al., 2018).

Modified DBI for Informing Calf Transactions

Potential exists to use an adapted version of the DBI as the unit of currency when trading calves. Adaptation is required, for example, because once the calf is born (i.e., when being sold), the monetary costs of calving performance (i.e., calving difficulty, gestation length, calf mortality) are already realized and therefore are of limited interest to the purchaser. Because the remaining traits are all moderately to highly heritable (Crowley et al., 2011; Pabiou et al., 2011a; Berry and Crowley, 2013), this means that the genetic merit of the calf should correlate well with its subsequent performance credentials. Moreover, it is the index value of the calf that is important and not that of the sire because (1) only half the genes of the calf originated from the sire, with the other half being inherited from the dam, and (2) a random half of genes is inherited from the sire, and thus paternal half-sib progeny can have considerably different index values. The economic values reported here can easily be applied for this purpose. Access to low-cost DNA screening tools (Boichard et al., 2012; Judge et al., 2016) provides a strategy to (1) verify parentage of each calf, (2) verify breed composition, and (3) generate more-accurate estimates of genetic merit for that calf. This DNA-based estimate can be supplemented with ancillary information such as calf sex, heterosis level, and dam parity to more accurately predict the expected total merit of the animal, as these have been proven to be associated with performance (Connolly et al., 2016). Such a system was proposed by Kelleher et al. (2015) when adapting a dairy cow breeding index into an index for the transaction of cows. This approach should aid in identifying, at a young age, animals that are most suitable for different production systems and markets.

CONCLUSIONS

Existing indexes available in Ireland are not efficient in identifying the best beef breed sires suitable for use in dairy heifers and cows. Essential to the establishment of a DBI was the incorporation of key nonlinear relationships for calving difficulty (dairy farmers will tolerate only a relatively low incidence of calving difficulty, irrespective of offsetting attributes) and for both carcass weight and conformation reflecting the very low carcass returns in Ireland from poorly conformed animals with light carcasses associated with some combinations of dairy and beef breeds. Introducing a DBI for ranking currently available beef bulls for use on dairy cows and heifers by AI should be a priority. However, this needs to be followed by the development of a breeding scheme dedicated to the identification of new AI sires and bulls for natural mating that rank highly for DBI, but with sufficient accuracy of prediction of genetic merit for calving difficulty so that dairy farmers are confident to use them. The index values of bulls could be updated with each national evaluation. The relative economic values should be re-examined routinely and updated where necessary.

ACKNOWLEDGMENTS

This publication has emanated from research supported by a research grant from Science Foundation Ireland and the Department of Agriculture, Food and Marine on behalf of the Government of Ireland under grant 16/RC/3835 (VistaMilk, Dublin, Ireland).

REFERENCES

Amer, P. R., G. Simm, M. G. Keane, M. G. Diskin, and B. W. Wickham. 2001. Breeding objectives for beef cattle in Ireland. Livest. Prod. Sci. 67:223–239.

Berry, D. P. 2018. Breeding a better cow—Will she be adaptable? J. Dairy Sci. 101:3665–3685.

Berry, D. P., S. Conroy, T. Pabiou, and A. R. Cromie. 2017a. Animal breeding strategies can improve meat quality attributes within entire populations. Meat Sci. 132:6–18.

Berry, D. P., A. R. Cromie, and M. M. Judge. 2017b. Rapid communication: Large exploitable genetic variability exists to shorten age at slaughter in cattle. J. Anim. Sci. 95:4526–4532.

Berry, D. P., and J. J. Crowley. 2013. Cell Biology Symposium: Genetics of feed efficiency in dairy and beef cattle. J. Anim. Sci. 91:1594–1613.

Berry, D. P., and R. D. Evans. 2014. Genetics of reproductive performance in seasonal calving beef cows and its association with performance traits. J. Anim. Sci. 92:1412–1422.

Berry, D. P., J. F. Kearney, K. Twomey, and R. D. Evans. 2013. Genetics of reproductive performance in seasonal calving dairy cattle production systems. Ir. J. Agric. Food Res. 52:1–16.

Berry, D. P., J. M. Lee, K. A. Macdonald, and J. R. Roche. 2007. Body condition score and body weight effects on dystocia and stillbirths and consequent effects on postcavling performance. J. Dairy Sci. 90:4201–4211.

Berry, D. P., F. E. Madalena, A. R. Cromie, and P. R. Amer. 2006. Cumulative discounted expressions of dairy and beef traits in cattle production systems. Livest. Prod. Sci. 99:159–174.

Boichard, D., H. Chung, R. Dassonneville, X. David, A. Eggen, S. Fritz, K. J. Gietzen, B. Hayes, C. T. Lawley, T. S. Sonstegard, C. P. Van Tassell, P. M. VanRaden, K. A. Viaud-Martinez, and G. R. Wiggans. 2012. Design of a bovine low-density SNP array optimized for imputation. PLoS One 7:e34130. https://doi.org/10.1371/journal.pone.0034130.

Cockerill, C. A. 2006. Is there a child health premium for the safety of children on farms?: Evidence from valuation and experimental studies. PhD Thesis. Faculty of Medicine, Health and Life Sciences. Queens University, Belfast, Ireland.

Connolly, S. M., A. R. Cromie, and D. P. Berry. 2016. Genetic differences based on a beef terminal index are reflected in future phenotypic performance differences in commercial beef cattle. Animal 10:736–745.

Crosson, P., P. O'Kiely, F. P. O'Mara, and M. Wallace. 2006. The development of a mathematical model to investigate Irish beef production systems. Agric. Syst. 89:349–370.

Crowley, J. J., R. D. Evans, N. McHugh, D. A. Kenny, M. McGee, D. H. Crews Jr., and D. P. Berry. 2011. Genetic relationships between feed efficiency in growing males and beef cow performance. J. Anim. Sci. 89:3372–3381.

Crowley, J. J., M. McGee, D. A. Kenny, D. H. Crews Jr., R. D. Evans, and D. P. Berry. 2010. Phenotypic and genetic parameters for different measures of feed efficiency in different breeds of Irish performance tested beef bulls. J. Anim. Sci. 88:885–894.

De Vries, A., M. Overton, J. Fetrow, K. Leslie, S. Eicker, and G. Rogers. 2008. Exploring the impact of sexed semen on the structure of the dairy industry. J. Dairy Sci. 91:847–856.

Dematawewa, C. M. B., and P. J. Berger. 1997. Effect of dystocia on yield, fertility, and cow losses and an economic evaluation of dystocia scores for Holsteins. J. Dairy Sci. 80:754–761.

Eaglen, S. A., and P. Bijma. 2009. Genetic parameters of direct and maternal effects for calving ease in Dutch Holstein-Friesian cattle. J. Dairy Sci. 92:2229–2237. https://doi.org/10.3168/jds.2008-1654.

Eaglen, S. A. E., M. P. Coffey, J. A. Woolliams, R. Mrode, and E. Wall. 2011. Phenotypic effects of calving ease on the subsequent fertility and milk production of dam and calf in UK Holstein-Friesian heifers. J. Dairy Sci. 94:5413–5423.

Englishby, T. M., G. Banos, K. L. Moore, M. P. Coffey, R. D. Evans, and D. P. Berry. 2016. Genetic analysis of carcass traits in beef cattle using random regression models. J. Anim. Sci. 94:1354–1364.

Evans, R. D., T. Pabiou, A. Cromie, F. Kearney, and B. Wickham. 2007. Genetic improvement in the Irish suckler beef herd: Industry expectation and experience so far. Accessed Aug. 14, 2014. https://journal.interbull.org/index.php/ib/article/download/926/917.

Evans, R. D., T. Pabiou, F. Kearney, and H. A. Mulder. 2009. Multi-breed genetic evaluation for docility in Irish suckler beef cattle. Accessed Nov. 16, 2014. https://journal.interbull.org/index.php/ib/article/view/1098/1089.

García-Ruiz, A., J. B. Cole, P. M. VanRaden, G. R. Wiggans, F. J. Ruiz-López, and C. P. Van Tassell. 2016. Changes in genetic selection differentials and generation intervals in US Holstein dairy cattle as a result of genomic selection. Proc. Natl. Acad. Sci. USA 113:E3995–E4004.

Gilmour, A. R., B. J. Gogel, B. R. Cullis, and R. Thompson. 2009. ASReml User Guide. Release 3.0. VSN International Ltd., Hemel Hempstead, UK.

Hayes, B. J., K. A. Donoghue, C. M. Reich, B. A. Mason, T. Bird-Gardiner, R. M. Herd, and P. F. Arthur. 2016. Genomic heritabilities and genomic estimated breeding values for methane traits in Angus cattle. J. Anim. Sci. 94:902–908.

Health and Safety Authority. 2019. Farm safety code of practice risk assessment document. Accessed May 5, 2019. https://www.hsa.ie/eng/Publications_and_Forms/Publications/Agriculture_and_Forestry/Farm_Safety_Code_of_Practice_Risk_Assessment_Document.pdf.

Jarrige, R. 1989. Ruminant Nutrition: Recommended Allowances and Feed Tables. Libbey, London, UK.

Judge, M. M., J. F. Kearney, M. C. McClure, R. D. Sleator, and D. P. Berry. 2016. Evaluation of developed low-density genotype panels for imputation to higher density in independent dairy and beef cattle populations. J. Anim. Sci. 94:949–962.

Judge, M. M., T. Pabiou, J. Murphy, S. Conroy, P. J. Hegarty, and D. P. Berry. 2019. Potential exists to change, through breeding, the yield of individual primal carcass cuts in cattle without increasing overall carcass weight. J. Anim. Sci. 97:2769–2779.

Kelleher, M. M., P. R. Amer, L. Shalloo, R. D. Evans, T. J. Byrne, F. Buckley, and D. P. Berry. 2015. Development of an index to rank dairy females on expected lifetime profit. J. Dairy Sci. 98:4225–4239.

Martin-Collado, D., F. Hely, T. J. Byrne, R. D. Evans, A. R. Cromie, and P. R. Amer. 2017. Farmer views on calving difficulty consequences on dairy and beef farms. Animal 11:318–326.

McCabe, S., R. Prendiville, R. Evans, N. E. O'Connell, and N. McHugh. 2019. Effect of cow replacement strategy on cow and calf performance in the beef herd. Animal 13:631–639.

Mc Hugh, N., A. G. Fahey, R. D. Evans, and D. P. Berry. 2010. Factors associated with selling price of cattle at livestock marts. Animal 4:1378–1389.

McNamara, J., B. Moran, and M. Cushion. 2007. National survey of farm accidents in Ireland. Page 125 in Proc. Irish Agricultural Research Forum, Tullamore, Ireland. Teagasc, OakPark, Carlow, Ireland.

Miglior, F., B. L. Muir, and B. J. Van Doormaal. 2005. Selection indices in Holstein cattle of various countries. J. Dairy Sci. 88:1255–1263.

Mujibi, F. D., and D. H. Crews Jr. 2009. Genetic parameters for calving ease, gestation length, and birth weight in Charolais cattle. J. Anim. Sci. 87:2759–2766.

Pabiou, T., W. F. Fikse, P. R. Amer, A. R. Cromie, A. Nasholm, and D. P. Berry. 2011a. Genetic variation in wholesome carcass cuts predicted from digital images in cattle. Animal 5:1720–1727.

Pabiou, T., W. F. Fikse, A. R. Cromie, M. G. Keane, A. Nasholm, and D. P. Berry. 2011b. Use of digital images to predict carcass cut yields in cattle. Livest. Sci. 137:130–140.

Philipsson, J., G. Banos, and T. Arnason. 1994. Present and future uses of selection index methodology in dairy cattle. J. Dairy Sci. 77:3252–3261.

Phocas, F., C. Bloch, P. Chapelle, F. Bécherel, G. Renand, and F. Ménissier. 1998. Developing a breeding objective for a French purebred beef cattle selection programme. Livest. Prod. Sci. 57:49–65.

Riley, D. G., C. C. Chase Jr., T. A. Olson, S. W. Coleman, and A. C. Hammond. 2004. Genetic and nongenetic influences on vigor at birth and preweaning mortality of purebred and high percentage Brahman calves. J. Anim. Sci. 82:1581–1588.

Robertson, A. 1959. The sampling variance of the genetic correlation coefficient. Biometrics 15:469–485.

Roche, J. R., D. P. Berry, L. Delaby, P. G. Dillon, B. Horan, K. A. Macdonald, and M. Neal. 2018. New considerations to refine breeding objectives of dairy cows for increasing robustness and sustainability of grass-based milk production systems. Animal 12:S350–S362.

Shalloo, L., A. R. Cromie, and N. McHugh. 2014. Effect of fertility on the economics of pasture-based dairy systems. Animal 8:222–231.

Shalloo, L., P. Dillon, M. Rath, and M. Wallace. 2004. Description and validation of the Moorepark Dairy Systems Model (MDSM). J. Dairy Sci. 87:1945–1959.

Strandén, I., and M. Lidauer. 1999. Solving large mixed linear models using preconditioned conjugate gradient iteration. J. Dairy Sci. 82:2779–2787.

van der Werf, J. H. J., L. H. van der Waaij, A. F. Groen, and G. de Jong. 1998. An index for beef and veal characteristics in dairy cattle based on carcass traits. Livest. Prod. Sci. 54:11–20.

Veerkamp, R. F., P. Dillon, E. Kelly, A. R. Cromie, and A. F. Groen. 2002. Dairy cattle breeding objectives combining yield, survival and calving interval for pasture-based systems in Ireland under different milk quota scenarios. Livest. Prod. Sci. 76:137–151.

Vinet, A., H. Leclerc, F. Marquis, and F. Phocas. 2018. Genetic analysis of calf health in Charolais beef cattle. J. Anim. Sci. 96:1246–1258.

Wolfová, M., J. Wolf, J. Přibyl, R. Zahrádková, and J. Kica. 2005. Breeding objectives for beef cattle used in different production systems: 1. Model development. Livest. Prod. Sci. 95:201–215.