Dressing percentage and the differential between live weight and carcass weight in cattle are influenced by both genetic and non-genetic factors[1]

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ABSTRACT: The objective of the present study was to quantify the genetic and non-genetic contributors to variability in both carcass dressing percentage and dressing difference (i.e., the difference between carcass weight and live weight immediately prior to slaughter) in young animals and cows. The datasets contained 18,479 young animals from 653 herds, and 2,887 cows from 665 herds. Live weight records within 7 d of slaughter and associated carcass weight were available for all animals. Association analyses were undertaken using linear mixed models with fixed effects for the model of young animals consisting of animal breed, days between the date of last recorded live weight and slaughter date, heterosis and recombination loss coefficients, dam parity, a 3-way interaction between whether the animal originated in a dairy or beef herd, animal sex, and age at slaughter, as well as a 2-way interaction between calendar year of slaughter and month of slaughter; contemporary group was included as a random effect. Fixed effects in the cow model were cow breed, the number of days between the date of last recorded live weight and slaughter date, heterosis and recombination loss coefficients, the number of days post-calving, parity of the cow, and a 2-way interaction between calendar year of slaughter and month of slaughter; contemporary group was included as a random effect. The mean dressing percentage (phenotypic standard deviation in parentheses) and dressing difference in young animals were 55.86% (3.21%) and 280.03 kg (41.44 kg), respectively. Steers had the heaviest dressing difference at 34.18 and 60.44 kg heavier than a 16-mo old bull and 22-mo old heifer, respectively. Dressing difference for 30-mo old Simmental steers (breed with heaviest dressing difference) was 41.66 kg heavier than 30-mo old Belgian Blue steers (breed with lightest dressing difference). The heritability of dressing percentage (0.48) and dressing difference (0.35) in young animals was relatively similar to each other, in contrast to dressing percentage (0.08) in cows which was considerably lower than dressing difference (0.28). Considerable genetic variability existed in dressing difference amongst young animals (genetic standard deviation of 15.03 kg), despite the near unity genetic correlation (0.93) between carcass weight and live weight. This therefore indicates that genetic selection for increased saleable product can be achieved by selecting for increased carcass weight while concurrently selecting for lighter animals although the opportunity is limited by the strong part-whole relationships that exists between carcass weight, live weight, and dressing difference.

Keywords: dressing percentage, dressing difference, cattle

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INTRODUCTION

Profitability in cattle production systems is a function of the value of the animal carcass, but also the cost of producing that carcass (Crosson et al., 2016). Dressing percentage, which is also sometimes referred to as kill-out percentage (Campion et al., 2009), reflects the carcass weight as a percentage of the overall live weight of the animal. A high dressing percentage is generally desirable as this implies a greater proportion of the live weight (i.e., a cost to producers) ends up as saleable yield (i.e., revenue). Being a percentage trait, however, a heavy live animal with a heavy carcass can have the same dressing percentage as a light live animal with a light carcass. While dressing percentage is the ratio of carcass weight to live weight, the fifth-quarter weight represents the sum of the visceral fat, alimentary tract, visceral organs, hide, feet, and head (Simóes et al., 2005). A heavy live animal or light live animal with the same dressing percentage can therefore have a very different fifth-quarter weight.

Many studies have attempted to quantify the genetic and non-genetic factors associated with interanimal variability in dressing percentage. Non-genetic factors documented to be associated with differences in dressing percentage include diet (Lovett et al., 2003; Walsh et al., 2008; Minchin et al., 2009b; Pesonen et al., 2012), age of the animal (Ríos-Utrera et al., 2005; Petrovic et al. 2017), gut fill (Bowling et al., 1978; Jones et al., 1985), and animal sex (Owens and Gardner, 2000). Breed differences in dressing percentage have also been documented (Alberti et al., 2008; Campion et al., 2009; Pesonen et al., 2012). Documented within-breed differences in dressing percentage have originated either from small controlled studies that compared different genotypes of animals (Campion et al., 2009; Clarke et al., 2009) or from variance components estimated in cross-sectional studies (Pariacote et al., 1998; Lee et al., 2000; Burrow et al., 2001). Heritability estimates for dressing percentage in cattle range from 0.12 to 0.86 (Pariacote et al., 1998; Lee et al., 2000; Burrow et al., 2001). Factors associated with the weight of the fifth-quarter weight are less well known in cattle and, to the best of our knowledge, no genetic parameters exist for fifth-quarter weight in cattle. Because no data generally exists for fifth-quarter weight nationally, a new trait was defined, herein referred to as dressing difference, representing the actual difference, in kg, between live weight and carcass weight. The dressing difference therefore represents the visceral fat, the alimentary tract (and its contents), visceral organs, hide, feet, blood and head which differs slightly (i.e., blood and gut fill) to the definition of fifth-quarter weight (Simóes at al., 2005).

The objective of the present study was to identify the genetic and non-genetic factors contributing to variability in both carcass dressing percentage and dressing difference in both young animals and cows separately. Results from this study could have important ramifications for breeding programs that are considering dressing percentage or dressing difference in their selection decisions.

MATERIALS AND METHODS

The data used in the present study were obtained from a preexisting database managed by the Irish Cattle Breeding Federation (ICBF). Therefore, it was not necessary to obtain animal care and use committee approval in advance of conducting this study.

Data

Carcass data were available on 13,929,856 animals slaughtered between the years 2008 and 2017, inclusive. The data comprised of 1,590,646 bulls, 5,584,329 steers, 3,704,906 heifers, and 3,049,975 cows; seventeen breeds were represented (mainly as crossbreds) in the dataset. Carcass information available included the date of slaughter, carcass weight (measured on average 2 h post-slaughter), carcass conformation, and carcass fat; both carcass conformation and carcass fat were appraised under the European Union (EU) beef carcass classification system as detailed by Pabiou et al. (2011). Carcass conformation and fat were graded on a 15-point scale (Englishby et al., 2016); a score of 1 in both scales reflects a poor conformation score and low fat score, with a score of 15 reflecting excellent conformation and a high level of fat cover. At least 1 live weight record was also available on 3,308,415 of the animals with carcass data. Date of birth, breed composition and heterosis (the advantage in performance of crossbred animals above the mid-parent mean [Simm, 2000]), and recombination loss coefficients (a loss in epistatic effects as a result of the breaking up of the linked loci in advanced generations in inbreeding hybrids [Lynch and Walsh, 1998]) of all animals were available. The parity number of all females (including dams) as well as information on inter-herd movements for each animal was also available.

Only animals with a known sire and at least 1 live weight record within 7 d of slaughter were considered further; data on 126,366 animals remained. Animals that moved herds more than 4 times during their lifetime or that resided for less than 70 d in the herd from which they were slaughtered were discarded. Dressing percentage was defined as carcass weight divided by the final live weight record of the animal and only animals with a dressing percentage between 40% and 70% were retained. Dressing difference was defined as the final live weight record of the animal minus the carcass weight.

The coefficient of heterosis and the coefficient of recombination loss were calculated for each animal as

$$1 - \sum_{i=1}^{n} sire_i.dam_i$$

and

$$1 - \sum_{i=1}^{n} \frac{sire_i^2 + dam_i^2}{2},$$

respectively, where $sire_i$ and dam_i are the proportion of breed i in the sire and dam, respectively (Van Raden, 1992; Van Raden and Sanders, 2003). Heterosis was divided into 12 classes (0%, 10 classes of 10% from 0% to 100%, exclusive, and 100%). Recombination loss was segregated into 7 classes (0%, 5 classes of 10% from 0% to 50%, exclusive, and 50%).The dataset was subsequently split into 1) young animals with no recorded progeny and 2) cows. The difference between dressing difference, as defined in the present study, and fifth-quarter weight is that dressing difference also includes the weight of the contents of the gastrointestinal tract as well as the weight of the blood.

Young animals. Only single-born offspring were retained. Furthermore, only bulls slaughtered between 14 and 24 mo of age, and steers and heifers slaughtered between 14 and 36 mo of age were retained. Animals were classified as either born in a dairy or beef herd based on the breed composition of their dam (Ring et al., 2018). The parity of each dam was categorized as 1, 2, 3, 4, and 5+. Contemporary groups of herd-sex-year-season of slaughter were defined based on an algorithm used in the Irish national genetic evaluation (Berry and Evans, 2014; McHugh et al., 2014; Berry et al., 2017) and described in detail by Berry and Evans (2014). Within each herd, animals of the same sex were clustered together based on the proximity of their slaughter dates (≤10 d); if there were <10 animals in the initial cluster, then the group was amalgamated with an adjacent group. This process was repeated, until there were ≤90 d between the initial and final slaughter date for the group and there were ≥10 animals in the contemporary group. Contemporary groups with less than 5 animals were removed; 68% of the contemporary groups were <30 d in duration. The final dataset contained 21,366 animals, of which 18,479 were young animals consisting of 6,302 bulls, 3,900 steers, and 8,277 heifers all from 1,347 different contemporary groups and 653 herds. Of the edited dataset, the overwhelming majority of the animals (92.54% of the animals) were beef crossbreds (breed component ≥ 50% of a beef breed). The major breed component of 95% of these beef crossbred animals was Charolais (44.85% of the animals), Limousin (32.66% of the animals), Simmental (7.22% of the animals), Aberdeen Angus (5.34% of the animals), or Belgian Blue (5.09% of the animals).

Cows. For the purpose of the present study, all cows of parity 10 or greater were not considered further. The parity of each cow was categorized as 1, 2, 3, 4, and 5+. Only cows slaughtered within 450 d of calving were retained, and days post-calving at slaughter were categorized into 10 groups of 30-d periods, i.e., <30, 30 to 59, 60 to 89 … 270 to 299 d, and then 2 groups of 100-d periods (i.e., 300 to 399 and 400 to 450 d). Contemporary groups were defined as herd-year-date of slaughter using the algorithm described in the previous section and only records from contemporary groups with a minimum of 3 animals were retained for analysis. The final dataset contained 2,887 cows from 779 contemporary groups in 665 herds; 46.1% of these were dairy cows. The major breed component of 90% of the beef cows was Limousin (33.85% of the beef crossbred cows), Charolais (26.51% of the beef crossbred cows), Simmental (13.26% of the beef crossbred cows), Aberdeen Angus (9.42% of the beef crossbred cows), or Hereford (7.02% of the beef crossbred cows).

Analysis

Linear mixed models were used to quantify the association between fixed effects and both the dressing percentage and dressing difference in the young animals and cows separately; in all models, contemporary group was fitted as a random effect. When the dependent variable was based on young animals, the fixed effects included in the model were dam parity, the number of days between the date of last recorded live weight and slaughter date, breed proportion of the animal fitted as a linear covariate representing each of the 8 main breeds (i.e., Limousin, Hereford, Charolais, Holstein-Friesian, Simmental, Belgian Blue, Aberdeen Angus, and Jersey) separately, a 3-way interaction between sex (i.e., young bull, steer, or heifer), whether the animal was born into a dairy or beef herd and month of age at slaughter, heterosis and recombination loss coefficients, and a 2-way interaction between calendar year of slaughter and month of slaughter. When the dependent variable was either dressing percentage or dressing difference in cows, the fixed effects included in the model were categorized days post-calving, heterosis and recombination loss coefficients, parity of the cow, breed proportion of the animal fitted as a linear covariate representing each of the 8 main breeds (i.e., Limousin, Hereford, Charolais, Holstein-Friesian, Simmental, Belgian Blue, Aberdeen Angus, and Jersey) separately, the number of days between the date of last recorded live weight and slaughter date, and a 2-way interaction between calendar year of slaughter and month of slaughter.

Least squares means for dressing percentage, dressing difference, live weight, and carcass weight in young beef animals were based on a reference animal defined as a purebred steer of the particular breed being analyzed, born into a beef herd, with a final live weight record 1 d prior to slaughter, from a third parity dam and slaughtered at 30 mo of age (i.e., average age at slaughter of steers in the edited dataset); the reference animal for a dairy bred young animal was as defined previously except that it was born in a dairy herd (as opposed to a beef herd as was the case for the beef-bred animals). The reference animal for the least square means estimation in cows was a third parity, purebred cow from the particular breed being analyzed, slaughtered 300 to 399 d post-calving, with a final live weight record 1 d prior to slaughter.

Variance component estimation. Variance components for dressing percentage, dressing difference, live weight, carcass weight, carcass conformation, and carcass fat were estimated using univariate linear mixed models in ASREML (Gilmour et al., 2009). The fixed effects in the model for young animals were contemporary group, the number of days between the date of last recorded live weight and slaughter date, heterosis and recombination loss coefficients, whether the animal originated in a dairy of beef herd, dam parity, and a 2-way interaction between carcass type and month of age at slaughter. The fixed effects in the model for cows were contemporary group, the number of days between the date of last recorded live weight and slaughter date, heterosis and recombination loss coefficients, the number of days post-calving, and the parity of the cow. A direct additive genetic effect was included as a random effect $N \sim (0,\mathbf{A}\sigma_a^2)$ along with a random residual $N \sim (0,\mathbf{I}\sigma_e^2)$ term in all models, where σ_a^2 is the additive genetic variance, σ_e^2 is the residual variance, **A** is the numerator relationship matrix, and **I** is an identity matrix. The pedigree of all animals was traced back to the founder population which was allocated to genetic groups based on breed. Correlations among dressing percentage, dressing difference, live weight, carcass weight, carcass conformation, and carcass fat were estimated using a series of bivariate analyses; the same model effects used for univariate analyses were implemented for both young animals and cows.

RESULTS

The young animals weighed, on average, 635.80 kg, had a dressing percentage of 56% and a dressing difference of 280 kg (Table 1). Steers were, on average, the heaviest live (689.56 kg) and oldest at slaughter (783 d), but the bulls had both the heaviest carcass weight (400.73 kg) and greatest dressing percentage (58%) overall. The cows weighed, on average, 699.90 kg with a mean dressing percentage of 49% (Table 1) and an average dressing difference of 358.50 kg. Phenotypically, irrespective of whether in cows or in young animals, better dressing percentage was associated with heavier carcasses, reduced dressing difference, and better conformation (Tables 2 and 3); a negative phenotypic correlation existed between dressing percentage and carcass fat in young animals but this correlation was positive in cows. Dressing percentage and dressing difference were moderately negatively phenotypically correlated with each other in the different animal sexes and ages varying from −0.57 in heifers to −0.36 in steers (Tables 2 and 3). Dressing difference was strongly phenotypically correlated with live weight (0.78 to 0.89) and moderately positively correlated with carcass weight (0.37 to 0.60). Dressing difference was not phenotypically associated with carcass conformation. A graphical illustration of the association between dressing difference and carcass weight in just steers slaughtered between 24 and 29 mo of age is in Figure 1; the residual standard deviation around the linear regression line was 30.18 kg implying considerable variability.

Non-genetic Factors

All fixed effects tested in the least squares means models were associated with both dressing percentage ($P < 0.01$) and dressing difference ($P < 0.05$) in

Table 1. Mean value, genetic standard deviation (σ_g), and heritability estimates (h^2; standard error in parentheses) for live and carcass traits on young animals and cows

Trait	Mean	σ_g	h^2
Young animals			
Dressing percentage, %	56	1.38	0.48 (0.04)
Dressing difference, kg	280.00	15.03	0.35 (0.03)
Live weight, kg	635.80	32.58	0.44 (0.03)
Carcass weight, kg	355.70	21.23	0.50 (0.03)
Carcass conformation, scale 1–15	8.98	0.78	0.45 (0.04)
Carcass fat, scale 1–15	6.50	0.91	0.56 (0.04)
Cows			
Dressing percentage, %	49	0.59	0.08 (0.08)
Dressing difference, kg	358.50	17.82	0.28 (0.11)
Live weight, kg	699.90	45.05	0.51 (0.11)
Carcass weight, kg	341.50	25.29	0.51 (0.11)
Carcass conformation, scale 1–15	5.33	0.58	0.24 (0.10)
Carcass fat, scale 1–15	7.67	1.14	0.42 (0.10)

Table 2. Phenotypic correlations between live and carcass traits in bulls (below diagonal) and steers (above diagonal)

	Dressing %	Dressing difference	Live weight	Carcass weight	Carcass conformation	Carcass fat
Dressing %		−0.36	0.18	0.55	0.68	−0.05
Dressing difference	−0.48		0.85	0.57	0.01^{NS}	0.19
Live weight	0.03	0.86		0.92	0.39	0.17
Carcass weight	0.41	0.60	0.92		0.60	0.12
Carcass conformation	0.58	0.02^{NS}	0.35	0.54		-0.03^{NS}
Carcass fat	−0.13	0.24	0.20	0.13	0.01^{NS}	

^{NS}Phenotypic correlation not different ($P > 0.05$) from zero.

young animals, with the exception of the heterosis effect which was not associated ($P = 0.747$) with dressing percentage. The mean dressing percentage was 0.68% (SED = 0.09%) higher in young animals born in beef herds relative to those born in dairy herds (after adjusting for differences in breed composition); the mean dressing difference was 3.52 kg (SED = 1.21 kg) lower in animals born in beef herds relative to animals born into dairy herds. Dressing percentage least squares means for a purebred Limousin bull, born into a beef herd, from a third parity dam and slaughtered at 16 mo of age was 59.24% (SE = 0.12%); for a purebred Limousin steer, born into a beef herd, from a third parity dam and slaughtered at 30 mo of age, the mean dressing percentage was 57.30% (SE = 0.16%); the mean dressing percentage of a purebred Limousin heifer, born into a beef herd, from a third parity dam and slaughtered at 22 mo was 56.09% (SE = 0.12%); the respective least squares means for dressing difference in bulls, steers, and heifers was 279.51 kg (SE = 1.50 kg), 313.69 kg (SE = 2.04 kg), and 253.25 kg (1.50 kg). Dressing percentage was greatest in Belgian Blues and poorest in Jersey (Table 4); no difference in dressing difference however existed between Belgian Blues and Jersey. Dressing difference was heaviest in Holstein-Friesians (Table 4).

Least squares means for dressing percentage by parity of dam is shown in Table 5. Progeny from a third parity dam had the greatest dressing percentage (57.30%; SE = 0.10%), whereas progeny from fourth parity dams, on average, had the heaviest dressing difference (294.75 kg; SE = 1.28 kg). Both dressing percentage and dressing difference in young animals increased with age at slaughter (Figure 2). The dressing percentage and dressing difference of a 13 mo old bull were 59.02% (SE = 0.25%) and 266.64 kg (SE = 3.20 kg), respectively, whereas the corresponding dressing percentage and dressing difference of a 24 mo old bull were 60.66% (SE = 0.28%) and 306.84 kg (SE = 3.68 kg).

The majority of fixed effects were significantly associated with both dressing percentage and dressing difference in cows; neither heterosis nor recombination effects were associated with either trait ($P > 0.05$). The Hereford breed proportion was not associated ($P = 0.287$) with dressing percentage and categorized days post-calving ($P = 0.073$),

Table 3. Phenotypic correlations between live and carcass traits in heifers (below diagonal) and cows (above diagonal)

	Dressing %	Dressing difference	Live weight	Carcass weight	Carcass conformation	Carcass fat
Dressing %		−0.40	0.25	0.70	0.82	0.27
Dressing difference	−0.57		0.78	0.37	−0.09	0.13
Live weight	−0.14	0.89		0.87	0.46	0.31
Carcass weight	0.30	0.60	0.90		0.76	0.36
Carcass conformation	0.51	0.04	0.33	0.54		0.31
Carcass fat	−0.18	0.29	0.25	0.16	−0.08	

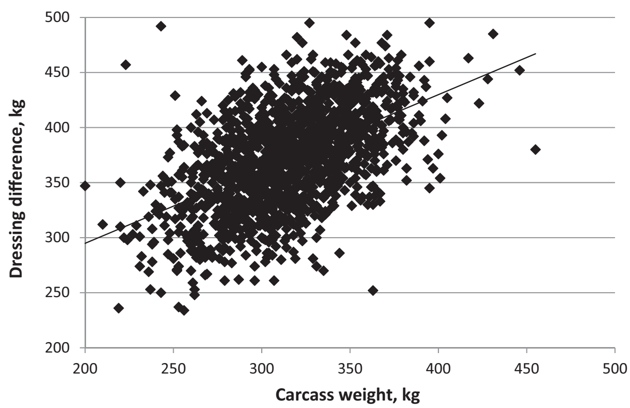

Figure 1. Phenotypic regression of dressing difference on carcass weight in steers slaughtered from 24 to 29 mo of age.

Belgian Blue proportion ($P = 0.162$), and Aberdeen Angus proportion ($P = 0.695$) were not associated with dressing difference. Dressing percentage and dressing difference least squares means for a third parity, purebred Limousin cow, slaughtered 300 to 399 d post-calving, with a final live weight record 1 d prior to slaughter were 54.43% (SE = 0.25%) and 326.45 kg (SE = 3.90 kg), respectively (Figure 3). Dressing percentage least square means were highest for a purebred Limousin cow (54.82%; SE = 0.33%) with a dressing difference of 323.06 kg (SE = 5.06 kg), which was the lowest of the beef breeds; overall, Jersey cows had the lowest least square means for dressing difference of 262.92 kg (SE = 13.07 kg; Table 4). First parity cows had the greatest dressing percentage of 54.76% (SE = 0.24%), with fifth parity cows having the heaviest dressing difference at 338.07 kg (SE = 3.14 kg; Table 5). Dressing percentage increased as days between calving and slaughter increased with the exception of the 150 to 179 d post-calving category (i.e., stage 6), where a reduction in dressing percentage was detected (Figure 3).

Genetic Parameters

The coefficient of genetic variation for dressing percentage was low in both young animals (3%) and cows (1%); the coefficient of genetic variation for dressing difference in both young animals and cows was 5%. The heritability of dressing percentage (0.48) and dressing difference (0.35) in young animals (Table 1) was relatively similar to each other but were also similar to the heritability estimates for live weight (0.44), carcass weight (0.50), carcass conformation (0.45), and carcass fat (0.56) estimated in the same population. The heritability of dressing percentage in cows (0.08) was considerably lower than the heritability of 0.28 for dressing difference. The heritability of the other carcass and live traits in cows were similar in magnitude to each other, ranging from 0.42 (carcass fat) to 0.51 (live weight and carcass weight) with the exception of carcass conformation which was moderately heritable (0.24).

Weak to moderate genetic correlations existed between dressing percentage and the other live and carcass traits in young animals ranging from −0.39 (dressing difference) to 0.69 (carcass conformation; Table 6). Genetically, irrespective of whether in young animals or cows, heavier dressing difference was associated with heavier live weight (Table 6); based on the estimated genetic correlation between dressing difference and live weight, and the associated genetic standard deviations, the slope of the genetic regression of live weight on dressing difference in young animals and cows was 1.84 and 2.50, respectively. Heavier live weight was strongly genetically correlated with heavier carcass weight in young animals (0.93) and cows (0.99; Table 6); based on the slope of the genetic regression of live weight on carcass weight, every 1 kg increase in carcass weight is expected to be associated with, on average, a 1.43 kg increase in live weight in young animals, and 1.54 kg in cows. In cows, dressing percentage was strongly genetically correlated with heavier dressing difference, live weight, and carcass weight, as well as better conformation (Table 6). Furthermore, near unity correlation estimates between dressing difference and both live weight (0.99) and carcass weight (0.98) suggest larger, heavier cows have, on average, larger dressing differences.

Table 4. Least squares means (standard error in parentheses) for dressing percentage (%), dressing difference (kg), live weight (kg), and carcass weight (kg) for both young animals and cows of the 8 main breeds Limousin (LI), Holstein-Friesian (HF), Jersey (JE), Aberdeen Angus (AA), Belgian Blue (BB), Charolais (CH), Hereford (HE), and Simmental (SI)

Trait	LI[1]	HF[2]	JE[2]	AA[1]	BB[1]	CH[1]	HE[1]	SI[1]
Young animals								
Dressing %	57.57[a] (0.16)	50.75[b] (0.20)	47.50[c] (0.89)	52.91[d] (0.18)	58.94[e] (0.20)	55.94[f] (0.16)	51.79[b] (0.19)	54.15[g] (0.17)
Dressing difference (kg)	291.22[a] (2.02)	337.79[b] (2.57)	274.53[a] (11.57)	307.28[c] (2.33)	287.84[a] (2.59)	323.03[d] (2.06)	324.86[d] (2.44)	329.50[b] (2.19)
Live weight (kg)	682.23[a] (4.00)	684.16[b] (5.07)	511.50[c] (22.86)	654.43[c] (4.61)	694.81[b] (5.12)	731.31[d] (4.06)	677.93[a] (4.83)	719.43[ef] (4.32)
Carcass weight (kg)	391.01[a] (2.46)	346.37[b] (3.12)	236.97[c] (14.04)	347.15[d] (2.83)	406.97[e] (3.15)	408.28[e] (2.50)	353.07[f] (2.97)	389.93[a] (2.66)
Cows[3]								
Dressing %	54.82[a] (0.33)	45.00[b] (0.31)	42.76[c] (0.85)	50.83[d] (0.38)	54.08[a] (0.72)	52.70[e] (0.34)	49.08[f] (0.42)	49.96[g] (0.39)
Dressing difference (kg)	323.06[a] (5.06)	370.28[b] (4.72)	262.92[c] (13.07)	347.50[d] (5.88)	327.90[ad] (11.00)	375.96[b] (5.21)	367.72[b] (6.36)	376.29[b] (6.00)
Live weight (kg)	713.65[a] (9.46)	673.09[b] (8.82)	459.52[c] (24.42)	705.91[ad] (10.98)	715.97[af] (20.55)	794.20[e] (9.73)	723.40[a] (11.88)	752.73[f] (11.21)
Carcass weight (kg)	390.59[a] (5.48)	302.81[b] (5.11)	196.61[c] (14.15)	358.41[d] (6.36)	388.07[af] (11.91)	418.24[e] (5.64)	355.69[d] (6.88)	376.44[f] (6.49)

[1]Reference young animal is a purebred steer of the particular breed being analyzed, born into a beef herd, from a third parity dam, and slaughtered at 30 mo of age.

[2]Reference young animal is a purebred steer of the particular breed being analyzed, born into a dairy herd, from a third parity dam, and slaughtered at 30 mo of age.

[3]Reference animal is a third parity, purebred cow of the particular breed being analyzed, slaughtered 300 to 400 d post-calving.

[a–g]Values with a different superscript within a row are statistically different ($P < 0.05$).

Table 5. Least squares means (standard error in parentheses) for dressing percentage (%), dressing difference (kg), live weight (kg), and carcass weight (kg) across different dam parities for young animals, and across different parity in cows

Trait	Parity 1	Parity 2	Parity 3	Parity 4	Parity 5
Young animals[1]					
Dressing %	57.10[a] (0.10)	57.25[bd] (0.10)	57.30[b] (0.10)	57.13[ae] (0.10)	57.20[cde] (0.09)
Dressing difference, kg	289.66[a] (1.25)	291.85[b] (1.25)	292.81[bd] (1.27)	294.75[c] (1.28)	293.21[d] (1.19)
Live weight, kg	671.48[a] (2.47)	678.58[b] (2.47)	681.62[c] (2.50)	683.73[c] (2.53)	681.01[c] (2.35)
Carcass weight, kg	381.72[a] (1.52)	386.64[b] (1.52)	388.72[c] (1.54)	388.88[c] (1.56)	387.71[bc] (1.44)
Cows[2]					
Dressing %	54.76[a] (0.24)	54.50[b] (0.23)	54.36[b] (0.23)	53.89[c] (0.23)	53.41[d] (0.21)
Dressing difference, kg	293.04[a] (3.74)	313.52[b] (3.49)	324.24[c] (3.48)	334.04[d] (3.47)	338.07[d] (3.14)
Live weight, kg	654.22[a] (6.99)	691.98[b] (6.52)	710.66[c] (6.51)	723.89[d] (6.48)	724.71[d] (5.87)
Carcass weight, kg	360.52[a] (4.05)	377.94[b] (3.78)	385.80[c] (3.77)	389.28[c] (3.76)	386.04[c] (3.40)

[1]Reference animal is a purebred Limousin steer, born into a beef herd, from a third parity dam, and slaughtered at 30 mo of age.

[2]Reference animal is a third parity, purebred Limousin cow, slaughtered 300 to 400 d post-calving.

[a–e]Values with a different superscript within a row are statistically different ($P < 0.05$).

DISCUSSION

The live animal at slaughter can be apportioned into the weight of the carcass and the remaining difference in weight between the live weight and the carcass weight, herein known as dressing difference. Most studies on carcass characteristics in cattle have focused on carcass weight with a paucity of studies attempting to quantify the genetic and non-genetic factors associated with either dressing difference or fifth-quarter weight. Tissues contributing to the fifth-quarter weight in cattle can be broadly categorized into edible or co-products (red offal including the liver, heart, kidney, and tail), and inedible by-products (green offal including the stomach, digestive tract, and hide). In the present study, no estimates were available for gut fill or blood volume, both of which constitute to the difference between the commonly used fifth-quarter weight and our definition of dressing difference. Nonetheless, the inclusion of contemporary group in the model should minimize the impact of gut fill on the results in that all animals in a given contemporary group are likely to, for example, have been exposed to the same diet and fed at the same time prior to slaughter as well as experience the same transport and lairage conditions prior to slaughter, all of which are

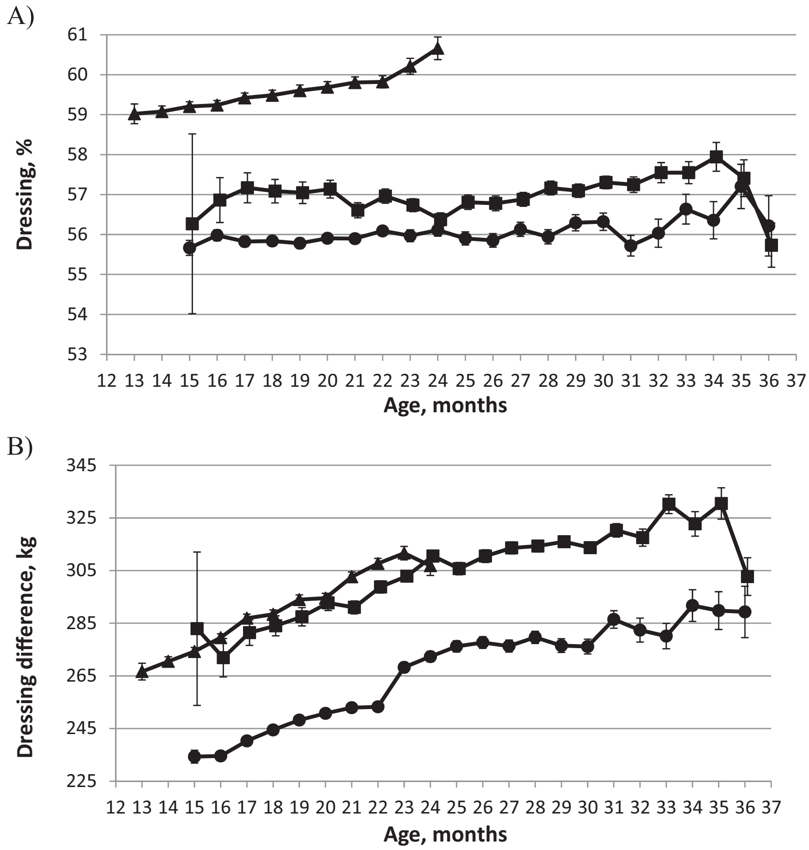

Figure 2. Least squares means and standard error values (standard error bar represents ±1 SE unit) for a purebred Limousin steer, born into a beef herd from a third parity dam, and slaughtered at 30 mo of age, for (A) dressing percentage and (B) dressing difference for heifers (circles), steers (squares), and bulls (triangles) at different months of slaughter.

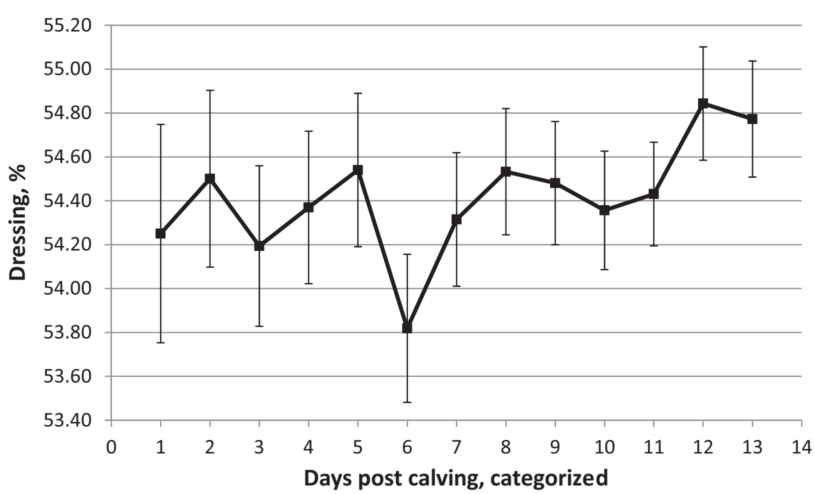

Figure 3. Least squares means and standard error values for a third parity, purebred Limousin cow, slaughtered 300 to 399 d postcalving for dressing percentage for cows at different stages postcalving.

likely to influence gut fill. Furthermore, the large dataset size should account for much of the difference across the factors of interest.

Producers generally receive no tangible value from the dressing difference although the cost of growing and maintaining this weight is bore by the producers. Therefore, there is an interest in increasing the amount or proportion of saleable product (or in other words the dressing difference); all else being equal, the outcome should be reduced costs but greater revenue. The objective, therefore, of the present study was firstly to identify the non-genetic factors associated with differences in carcass dressing percentage and dressing difference in both

Table 6. Genetic correlations (standard errors in parentheses) between live and carcass traits in young animals (below diagonal) and cows (above diagonal)

	Dressing %	Dressing difference	Live weight	Carcass weight	Carcass conformation	Carcass fat
Dressing %		0.75 (0.52)	0.81 (0.36)	0.85 (0.25)	0.99 (0.16)	−0.32 (0.33)
Dressing difference	−0.39 (0.05)		0.99 (0.02)	0.98 (0.06)	0.74 (0.20)	0.13 (0.22)
Live weight	0.16 (0.06)	0.85 (0.02)		0.99 (0.01)	0.84 (0.12)	0.04 (0.18)
Carcass weight	0.52 (0.04)	0.58 (0.04)	0.93 (0.01)		0.90 (0.09)	−0.03 (0.18)
Carcass conformation	0.69 (0.04)	−0.02 (0.06)	0.38 (0.05)	0.59 (0.04)		0.10 (0.22)
Carcass fat	−0.19 (0.05)	0.31 (0.05)	0.21 (0.05)	0.11 (0.05)	−0.08 (0.06)	

young animals and cows separately, and secondly to partition the total variance into a genetic component and a non-genetic component. Although a paucity of studies exist on the non-genetic factors associated with fifth-quarter weight in young animals (Simóes et al., 2005), no study exists on the genetics of dressing percentage or dressing difference in cows. Of the studies in cattle that attempted to partition the phenotypic variance in dressing percentage into genetic and non-genetic components (Pariacote et al., 1998; Lee et al., 2000; Burrow et al., 2001; Riley et al., 2002), the present study is one of the largest.

Non-genetic Factors Associated With Dressing Percentage and Dressing Difference

Studies that have attempted to quantify the factors associated with dressing percentage in cattle have generally been confined to small studies with limited numbers of young animals (Gregory et al., 1994; Wheeler et al., 1996; Wulf et al., 1996; Burrow et al. 2001); most of the studies were also confined to steers (Gregory et al., 1994; Wheeler et al., 1996; Burrow et al., 2001). A review by Owens and Gardner (2000) used data from 552 published research trials and quantified the degree to which diet, breed differences, and age at slaughter were associated with or affected dressing percentage in young animals. Corroborating the results from the present study, Owens and Gardner (2000) reported a sex effect on dressing percentage in young animals with the dressing percentage in steers being higher than in heifers. Results in direct contrast with the present study were published by Petrovic et al. (2017) who reported no significant difference in dressing percentage in young Simmental bulls slaughtered between 22 and 27 mo versus those slaughtered between 28 and 37 mo of age; these bulls however were considerably older than the range of 16 to 22 mo of age at slaughter used in the present study. Petrovic et al. (2017) concluded that higher dressing percentages could be achieved by crossbreeding Simmental cattle with French fattening breeds of Charolais, Limousin, and Blonde D'Aquitaine; it is well documented that these late maturing breeds have superior carcass conformation and dressing percentage (Kempster et al., 1982; Keane and Drennan, 2008). With regard to cows, Minchin et al. (2009b) reported that the 4 dietary treatments they investigated had no association with dressing percentage in Holstein-Friesian cows; the dietary treatment imposed included grass silage fed exclusively, grass silage fed with 3 kg of concentrate/d, grass silage fed with 6 kg of concentrate/d, and grass silage fed with 9 kg of concentrate/d.

To the best of our knowledge, no study has investigated dressing difference at either a phenotypic or genetic level in young animals or cows. The strong positive phenotypic correlations reported in the present study between dressing difference and live weight in young animals (0.85 to 0.89) suggest that factors affecting dressing difference in young animals are likely similar to the documented factors affecting live weight (Koenen et al., 1999; Berry et al., 2002; Campion et al., 2009).

Breed Differences in Dressing Percentage

Results from the present study clearly demonstrated that beef breeds, Limousin, Aberdeen Angus, Belgian Blue, Charolais, Hereford, and Simmental had, on average, higher dressing percentage than the dairy breeds investigated (i.e., Holstein-Friesian and Jersey); such a difference in dressing percentage among beef breed-type versus dairy-type breeds is well-documented in the literature (Cuvelier et al., 2006; Keane and Drennan, 2008; Campion et al., 2009; Bittante et al., 2018). The differences in dressing percentage observed in the present study among beef breeds are also in line with other international studies, where Limousin cattle had higher reported dressing percentages than the Aberdeen Angus breed (Alberti et al., 2008; Pesonen et al., 2012). Cuvelier et al. (2006) reported higher dressing percentages for young Belgian Blue bulls compared with Limousin and Aberdeen Angus breeds; this is similar to the respective differences in these breeds for dressing percentage observed in the present study, albeit the dressing percentage values for bulls, steers, and heifers in the present study were lower in magnitude than in Cuvelier et al. (2006).

Minchin et al. (2009a) analyzed cull cow carcass characteristics on 2,163 cows that were categorized into Friesian cows, early maturing breeds (Aberdeen Angus, Hereford, and Shorthorn) or late maturing breeds (Charolais, Limousin, Simmental, and Belgian Blue). Minchin et al. (2009a) reported that Friesian dairy cows had the lowest dressing percentage, with the early maturing breeds being intermediate while late maturing breeds had the highest dressing percentage of the 3 cow types.

Potential to improve dressing efficiency through breeding

Genetic variability, amongst other factors, dictates the rate of genetic gain (Rendel and Robertson, 1950) and the evidence from the present study indicates little within-breed genetic variability exists in dressing percentage in both young animals and cows; large exploitable between-breed differences however do exist. The within-breed coefficient of genetic variability in dressing percentage of 1% to 2% is considerably lower than documented for other performance traits in cattle, namely, carcass weight, conformation or fat score (6% to 15%—the present study; 5.8% to 12.5%—Pabiou et al., 2011), live weight (5% in young animals and 6% in cows—the present study; 9.7%—Pariacote et al., 1998), fertility (2% to 7%—Berry et al., 2014), and milk production (6% to 8%—Berry et al., 2003 and Carthy et al., 2016). The existence of little within-breed genetic variability in dressing percentage among young animals was evident from firstly the small genetic standard deviation for dressing percentage and secondly the near unity genetic correlation of 0.93 between live weight and carcass weight. Nonetheless, the genetic correlation of 0.58 between dressing difference and carcass weight suggests potential to reduce dressing difference and increase carcass weight simultaneously. In fact, based on the parameters estimated in the present study, a genetic standard deviation of 12.24 kg exists in dressing difference which is genetically independent of carcass weight. This is despite the part-whole relationships that exist between carcass weight, live weight, and dressing difference (Table 6). The genetic correlation with dressing difference was stronger with live weight than with carcass weight reflecting the larger genetic variance in the former (Table 1).

The lack of much within-breed genetic variability in dressing percentage for cows was also evident, epitomized by the almost unity genetic correlations between carcass weight and live weight of 0.99 in the present study. Although genetic variation existed for dressing difference in cows, the genetic correlation of 0.98 with carcass weight further indicates little potential to simultaneously increase carcass weight but reduce dressing difference (i.e., alter dressing percentage); a genetic standard deviation of only 3.55 kg existed for dressing difference genetically independent of carcass weight.

In fact, the within-breed genetic variability in dressing difference could also be calculated as the sum of the genetic variance in live weight and carcass weight minus twice the covariance between them. Nonetheless, in many countries, individual animal observations on both live weight and carcass weight are available; thus, the cost of generating genetic evaluations for dressing percentage would be expected to be minimal. Because dressing percentage in young animals at least is moderately heritable (0.48), excessive data are not required to achieve high accuracy of selection but also the trait is not sex limited and is available early in the lifetime of an individual (and its progeny).

The relatively little within-breed genetic variability for dressing percentage in young animals is relatively consistent with previous studies in cattle; the present study is the first, to the best of our knowledge, to document genetic parameters for dressing percentage in adult cows. Based on the information provided by Riley et al. (2002) from young Brahman cattle, the coefficient of genetic variation for dressing percentage in the young heifers and steers was 2.5% which is similar to the values of 1.2% to 2.7% calculated from the information provided by Lee et al. (2000) from Korean native cattle. Corroborating the results from the present study, dressing percentage in young animals has generally been quoted to be moderately heritable (0.12 to 0.86; Pariacote et al., 1998; Lee et al., 2000; Burrow et al., 2001; Riley et al., 2002). Nevertheless, a genetic standard deviation of 1.38 percentage units still exists for dressing percentage in the present study implying that genetic change is still possible, especially if the cost of generating such a genetic evaluation is low. The genetic standard deviation of 1.38 percentage unit implies a mean within-breed difference in dressing percentage of 3.86 units between the top 20% and bottom 20% on genetic merit for dressing percentage; this within-breed mean difference increases to 4.8 when comparing the top and bottom 10%. Assuming a mean live weight of 635.8 kg, a difference of 4.8 units in dressing percentage equates to 30.7 kg in carcass weight or 8.6% relative to the mean carcass weight in the present study. Such a difference is substantial.

The lack of considerable within-breed genetic variability in dressing percentage, especially in cows, creates an opportunity for the genetic evaluation of cow maintenance approximation in the absence of actual phenotypic cow live weight data. Carcass weight of cull cows once slaughtered is, however, often available. Furthermore, the lack of extensive within-breed genetic variability in dressing percentage, owing to the near unity genetic correlation between live weight and carcass weight in cows (0.99), carcass weight in cows could be used instead of live weight. The genetic variance in cow live weight however was 3.17 times that of carcass weight, and therefore, breeding values estimated for cow carcass weight may need to be rescaled if used as a substitute for cow live weight.

CONCLUSION

To the best of our knowledge, this study is the first to report both genetic and non-genetic parameters contributing to variability in dressing percentage and dressing difference in both young animals and cows. Genetic variation exists for dressing percentage and dressing difference in both young animals and cows. Further use of the phenotypes derived in the present study for management and breeding decisions would necessitate animals being weighed directly before slaughter. Considering the potential economic contribution of increasing dressing percentage and reducing dressing difference to beef production profitability, these parameters could be useful in helping design beef breeding programs.

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