

Genetic Evaluation of Body Weight of Lactating Holstein Heifers Using Body Measurements and Conformation Traits

E.P.C. KOENEN¹ and A. F. GROEN

Wageningen Institute of Animal Sciences, Animal Breeding and Genetics Group,
PO Box 338, 6700 AH Wageningen, The Netherlands

ABSTRACT

Genetic and phenotypic parameters of body weight (BW), hip height, heart girth, and linear conformation traits were estimated from field data for 7344 lactating Holstein heifers from 560 herds. Mean BW was around 540 kg at calving, decreased to a minimum of 514 kg by wk 6, and increased to >590 kg by wk 45 of lactation. The statistical model for BW included month of recording, lactation stage, pregnancy stage, proportion of Holstein genes, parity of the dam, calving age, herd, and animal. Variation between herds accounted for 33% of the phenotypic variation of BW. Estimated heritability was 0.33 for BW and ranged from 0.32 to 0.54 for heart girth, hip height, and conformation traits. Genetic correlations of BW with heart girth, hip height, body depth, rump width, and muscularity ranged from 0.48 to 0.77. The accuracy of a selection index was 0.90 for direct selection and 0.83 for indirect selection using information on those conformation traits of 50 daughters. Genetic variation of BW is considerable, and genetic evaluation of BW can be based on data for conformation traits from a field recording system with only a limited loss of accuracy.

(**Key words:** body weight, body measurements, conformation, heifers)

INTRODUCTION

For dairy cattle, BW has a negative economic value (3, 4, 22). Inclusion of BW in an aggregate genotype or breeding goal is only effective in terms of changing genetic trends when BW measurements on potential breeding animals or their relatives are also in the information index (5). Currently BW is not included in most breeding schemes for dairy cattle. To include BW in such a breeding scheme, a suitable recording method has to be available, and weighing large

groups of animals is not common practice. Therefore, traits that are already included in a regular recording scheme, such as body measurements or conformation traits, might be used as predictors of BW (7, 21). Moreover, for genetic evaluation, appropriate genetic and phenotypic parameters of BW have to be known. Reported heritabilities of BW for Holstein cattle were moderate to high and were mostly based on data from single experimental herds during limited lactation periods (20, 21). Heritability estimates for BW from field data are scarce. Ahlborn and Dempfle (1) analyzed subjective scores for BW of heifers and found a heritability of 0.24. Hietanen and Ojala (8) estimated BW using heart girth measurements and found a heritability of 0.13 for heifers. At present, knowledge is limited about field recording of BW and about genetic and phenotypic parameters of BW.

This study estimated genetic and phenotypic parameters of BW of field data and studied possibilities for genetic evaluation of BW using observations on body measurements and linear conformation traits.

MATERIALS AND METHODS

Data

From September 1995 through March 1996, BW, hearth girth, hip height, and linear conformation traits were collected for 7344 lactating Holstein heifers from 560 herds; the number of heifers per herd ranged from 3 to 65. Conformation traits were linearly scored by eight classifiers of the Royal Dutch Cattle Syndicate, and BW and heart girth were measured by seven persons specifically trained for this experiment. Scores for body depth, rump width, muscularity, and udder depth ranged from 1 to 9, and size and dairy character scores ranged from 65 to 100 (Table 1). For each trait, heifers were evaluated only once. In the final data file, observations for each conformation trait were standardized to an equal standard deviation within classifiers to account for differences in variation between classifiers. Observa-

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¹Corresponding author.

TABLE 1. Descriptions, unadjusted phenotypic means, standard deviations, and ranges for BW, body measurements, and conformation traits (n = 7344).

Trait	\bar{X}	SD	Range
BW, kg	546	56.5	373–855
Hearth girth, cm	192.9	7.34	166–222
Hip height, cm	141.7	3.72	126–157
Body depth ¹	5.23	1.57	1–9
Rump width	4.87	1.50	1–9
Muscularity	4.71	1.67	1–9
Udder depth	4.76	1.36	1–9
Size ²	80.9	4.30	65–89
Dairy character ²	80.5	3.71	65–92

¹Scales: body depth (1 = shallow to 9 = deep), rump width (1 = narrow to 9 = wide), muscularity (1 = poor to 9 = strong), and udder depth (1 = deep to 9 = shallow).

²Scores ranged from 65 to 100.

tions on body depth, rump width, muscularity, and udder depth were adjusted to a standard deviation of 1.50 points; observations on size and dairy character were adjusted to a standard deviation of 4.00 points. Age at calving was on average 795 d \pm 75 and ranged from 522 to 1090 d. Mean stage of lactation at measurement was 129 \pm 82 d. Mean production records for milk, fat, and protein were 7113, 312, and 247 kg, respectively, for a 305-d lactation.

Statistical Analysis

Observations on BW, heart girth, hip height, and linear conformation traits were described by the following models:

$$BW_{ijklmno} = MO_i + LAC_j + PREG_k + HF_1 + PARI_m + \alpha AGE + H_n + ANI_o + e_{ijklmno}$$

$$HG_{ijklmpno} = MO_i + LAC_j + PREG_k + HF_1 + PARI_m + PERS_p + \alpha AGE + H_n + ANI_o + e_{ijklmpno}$$

$$HT_{ilqmno} = MO_i + HF_1 + CLAS_q + PARI_m + \alpha AGE + H_n + ANI_o + e_{ilqmno}$$

$$CT_{ijlqno} = MO_i + LAC_j + HF_1 + CLAS_q + \alpha AGE + H_n + ANI_o + e_{ijlqno}$$

where

$$BW_{ijklmno} = \text{BW (kilograms),}$$

$$HG_{ijklmpno} = \text{heart girth (centimeters),}$$

$$HT_{ilqmno} = \text{hip height (centimeters),}$$

$$CT_{ijlqno} = \text{conformation trait,}$$

$$MO_i = \text{fixed effect of month of scoring (September through March),}$$

$$LAC_j = \text{fixed effect of stage of lactation (j = 1 to 21),}$$

$$PREG_k = \text{fixed effect of stage of pregnancy (k = 1 to 6),}$$

$$HF_1 = \text{fixed effect of the genetic group (1 = 1 to 4),}$$

$$PARI_m = \text{fixed effect of parity of the dam (m = 1 to 2),}$$

$$CLAS_q = \text{fixed effect of classifier (q = 1 to 8),}$$

$$PERS_p = \text{fixed effect of person (p = 1 to 7),}$$

$$\alpha = \text{regression coefficient,}$$

$$AGE = \text{age at calving (days),}$$

$$H_n = \text{random effect of herd (n = 1 to 560),}$$

$$ANI_o = \text{random effect of animal, and}$$

$$e_{ijklmno} = \text{random residual term.}$$

Four genetic groups were defined according to percentage of Holstein genes (≤ 62.5 , 75, 87.5, and 100%). Grouping did not only account for additive effects but also might have corrected for possible heterosis effects and recombination losses. Seven months of scoring were used: September through March. Stage of lactation was defined in the model as 21 biweekly periods: wk 1 to 2, wk 3 to 4, . . . , wk 39 to 40, and wk ≥ 41 . Stage of pregnancy was divided into six groups: ≤ 3 mo, 4 mo, 5 mo, 6 mo, 7 mo, and ≥ 8 mo pregnant. Effect of pregnancy on BW was expected to be minimal during the first 3 mo of calving (2). Two parity classes were defined: parity 1 or parity ≥ 2 of the dam. Significance ($P < 0.05$) of the fixed effects in each model was tested by the MIXED procedure of SAS (19). To account for genetic relationships, a matrix of additive genetic relationships including parents and grandparents of the heifer was included. The 736 bulls included in the data sired on average 9.6 daughters; the number of daughters per sire ranged from 1 to 1463. Estimates for the variance components were obtained by a REML method using a derivative-free algorithm (15). Genetic and phenotypic correlations among traits were estimated from bivariate analyses using starting values for the variances from the univariate analyses. Restarts using the estimates were used to test whether a global maximum was found for the $-2 \log(\text{likelihood})$. Standard errors of genetic correlations were approximated according to methods of Falconer (6).

The accuracy of selection for BW in a field recording scheme was evaluated by comparing selection indexes including direct or indirect measurements of BW for different progeny group sizes.

RESULTS

To illustrate the BW change during lactation, unadjusted means for phenotypic observations are presented on a weekly basis in Figure 1. The number of observations in a week ranged from 22 to 296.

TABLE 2. Estimated additive genetic variance (σ_a^2), herd variance (σ_c^2), error variance (σ_e^2), relative herd variance (c^2), and heritability of BW, body measurements, and linear conformation traits.

Trait	σ_a^2	σ_c^2	σ_e^2	c^2	h^2
BW	813.7	828.4	850.5	0.33	0.33 ¹
Heart girth	14.11	8.86	19.3	0.21	0.33
Hip height	7.11	1.63	4.41	0.12	0.54
Body depth	0.906	0.129	1.05	0.06	0.43
Rump width	0.713	0.177	1.36	0.08	0.32
Muscularity	0.994	0.186	1.09	0.08	0.44
Udder depth	0.784	0.203	1.27	0.09	0.35
Size	8.03	1.77	5.61	0.12	0.52
Dairy character	6.86	1.18	7.26	0.08	0.45

¹Estimated standard errors of the heritabilities range from 0.04 to 0.07.

Mean BW at calving was around 535 to 540 kg, decreased to a minimum of 514 kg in wk 6, and increased to >590 kg at the end of the lactation. The estimated regression coefficient of BW on age at calving was 0.21 kg/d. The BW of heifers having a multiparous dam was about 11 kg higher than that of heifers having a primiparous dam. Estimates for the effect of pregnancy on BW ranged from 2.1 kg when heifers were 4-mo pregnant to 28 kg when ≥8-mo pregnant. Estimates for the effect of the proportion of Holstein genes were 0, -1.23, -1.09, and -0.73 kg for the classes ≤62.5, 75, 87.5, and 100% Holstein, respectively.

Heritability estimates for BW, heart girth, and hip height were 0.33, 0.33, and 0.54, respectively (Table 2). Heritabilities of linear conformation traits ranged from 0.32 to 0.52. Relative herd variance was moderate for BW (0.33) and heart girth (0.21) but low for other traits (0.06 to 0.12). Genetic correlations among BW, heart girth, hip height, and conformation

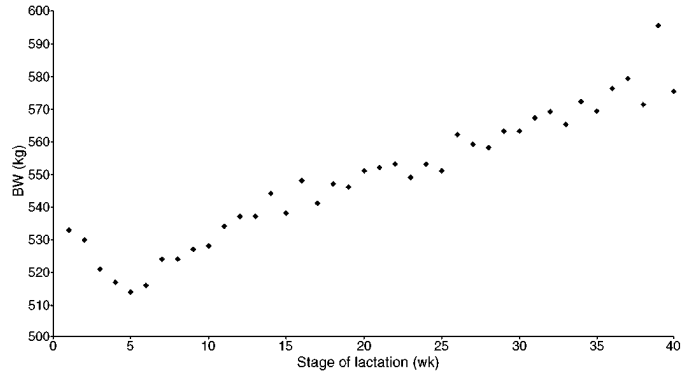


Figure 1. Mean unadjusted BW (♦) of heifers during lactation.

traits are shown in Table 3. Heart girth has the highest genetic correlation with BW ($r = 0.77$). Genetic correlations of BW with hip height, body depth, rump width, muscularity, and size were 0.50, 0.48, 0.43, 0.58, and 0.59, respectively. Hip height and size had a high genetic correlation ($r = 0.95$).

The accuracy of a selection index based on 50 effective daughters was 0.90 for direct BW measurements and 0.79 when observations on hip height, body depth, rump width, and muscularity were used (Table 4). These conformation traits are presently included in the regular scoring system in the Netherlands, but BW and heart girth are not. When information on heart girth was added, the accuracy of selection increased to 0.83.

DISCUSSION

Mean BW of heifers in our study was 546 kg and was much larger than the mean BW of 356-kg Holstein heifers in New Zealand (1) and the mean BW of

TABLE 3. Genetic (below diagonal) and phenotypic correlations (above diagonal) for BW, body measurements, and conformation traits.

	BW	HG	HT	BD	RW	MU	UD	SI	DC
BW									
HG ¹	0.77 ²								
HT	0.50	0.51							
BD	0.48	0.44	0.33						
RW	0.43	0.35	0.38	0.43					
MU	0.58	0.31	-0.15	0.08	0.16				
UD	-0.18	-0.02	0.32	-0.49	-0.26	-0.15			
SI	0.59	0.60	0.95	0.49	0.45	-0.10	0.16		
DC	0.15	0.14	0.65	0.56	0.25	-0.47	-0.01	0.70	

¹HG = Heart girth, HT = hip height, BD = body depth, RW = rump width, MU = muscularity, UD = udder depth, SI = size, and DC = dairy character.

²Estimated standard error of the genetic correlations range from 0.01 to 0.11.

TABLE 4. Accuracy of selection for three alternative selection indexes for BW based on 10, 25, 50, 100, and 200 effective daughters.

Trait	Effective daughters				
	10	25	50	100	200
BW	0.69	0.83	0.90	0.95	0.97
HT ¹ + BD + RW + MU	0.62	0.74	0.79	0.83	0.85
HT + BD + RW + MU + HG	0.65	0.77	0.83	0.87	0.89

¹HT = Hip height, BD = body depth, RW = rump width, MU = muscularity, and HG = hearth girth.

473 kg in Finland (8). Mean BW in our study is in line with results from North America. Hoffman (9) reviewed seven studies of Holstein replacement heifers and found a mean postpartum (0 to 7 d) BW of 559 kg and a mean BW of 532 kg at 30 d postpartum.

The effect of lactation was modeled using fixed effect classes (i.e., shape of the BW curve as a function of time was assumed to be equal for all heifers). Maltz et al. (13) found different BW curves for low and high producing heifers. To evaluate the effect of production on BW, heifers with the 25% lowest (< 6319 kg) and the 25% highest (>7861 kg) 305-d yield were compared. Mean unadjusted BW of low producing heifers was lower ($P < 0.01$) than that of high producing heifers (533 vs. 561 kg). However, after adjustment for the mean group effect, estimates for the stage of lactation did not differ between the groups ($P > 0.05$).

Holstein heifers in this study originated from an upgraded Dutch Friesian population. Variation in BW between different genetic groups might exist as the Holstein is a more dairy-oriented breed than the Dutch Friesian (17). No systematic trend was found for BW when the proportion of Holstein genes increased. However, hip height and scores for body depth, size, and dairy character increased as Holstein proportion increased, but scores for muscularity decreased. The increase in BW as a correlated response by increased height, body depth, size, and dairy character seemed to be compensated by decreased muscularity of the Holstein breed (17).

The relative effect of a multiparous dam on BW of around 2% (11 kg) that was found in this study was in line with an increase of 1.5% for BW at calving found by Koenen and Groen (11). For BW at birth, an increase of 5 to 10% from first to later parity has been reported (10, 14).

Variation between herds accounted for 33% of the total phenotypic variation of BW, which was in agreement with an estimate of 35% of Hietanen and Ojala (8). This variation might be due to variation in nutrition and management during the rearing period and variation in the time period between the weighing and the last milking of the heifers.

When heritability estimates of this study are compared with literature values, it should be noted that herd was treated as a random effect in the model. When data were reanalyzed treating herd as a fixed effect, estimates for additive and error variance were close to the original estimates. However, heritability estimates increased for herds treated as fixed, especially when herd variance was large. The heritability estimate of BW in this study was considerable higher than other estimates based on field data using indirect measurements (1, 8) but were, in most cases, lower than in studies based on actual weights of heifers of single herds (20, 21). Estimated heritabilities for conformation traits were in line with earlier estimates of the Dutch Friesian population (12).

In this study, parameters for heifer BW were estimated; in earlier studies on breeding goals, mostly mature BW was considered (4). However, high genetic and phenotypic correlations have been found between BW observations at different ages (11, 18), suggesting that heifer BW is a proper information source for the breeding goal mature BW.

To evaluate the effect of inclusion of BW in the breeding goal on genetic responses, genetic relationships with other traits such as milk production, feed intake, and body condition scores have to be considered simultaneously. Genetic correlations of BW with production traits were generally reported to be positive and low (1, 8) and to depend on lactation stage (16, 20).

Positive correlations between BW and body condition score (21, 23) suggest that selection for a decreased BW might result in an unfavorable decrease in body condition score. Because body condition is independent of frame size (23), the correlated response in body condition score might be minimal when genetic evaluation for BW is based on traits related to skeletal measurements, such as height rump width, and body depth. Incorporation of measures of skeletal growth when defining body size was also suggested by Hoffman (9) because BW per se might not be an appropriate measure of size.

CONCLUSIONS

The BW of heifers have considerable genetic and phenotypic variation. Routine genetic evaluation of BW can be based on indirect measurements such as conformation traits rather than on direct measurement of BW with only a limited loss of accuracy.

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