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The application of Legendre Polynomials to model muscularity and body condition score in primiparous Italian Simmental cattle

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ABSTRACT

The aim of the present study was to develop a model to predict muscularity and body condition score (BCS) during the lactation of Italian Simmental dairy cows in Emilia Romagna herds. A total of 2656 Italian Simmental primiparous cows from 324 dairy herds were linear classified between 2002 and 2020. Lactation curves for muscularity and BCS were modelled for each cow using random regression model. The model included the fixed effects of age at linear scoring and days in milk modelled with a Legendre polynomial, and the random effects of herd-year of classification, cow and days in milk for each cow modelled with Legendre polynomials. The most parsimonious model included a fixed cubic Legendre polynomial and a random linear polynomial for cow effects. Results indicated that, on an average, BCS nadir was anticipated to that of muscularity, and, in both cases, this moment was around the lactation peak, when animals have the greatest nutrients requirement. After this period, both BCS and muscularity recovered up to post-partum levels. Moreover, after the 9 month of lactation, the absolute growth rate of muscularity and BCS was negative, suggesting that late-gestating cows could potentially enter a phase of body conformation loss. Results reported in the current research indicate that random regression using Legendre polynomials can be successfully employed to predict muscularity and BCS during the lactation of dairy cows.

HIGHLIGHTS

- Modelling dairy cows' muscularity and BCS allows to use these parameters as indicator traits for functionality in dairy cows.
- The use of prediction model of muscularity and BCS allows to understand the evolution of these conformation traits during the lactation.
- The analysis of muscularity and BCS allows to assess health and welfare status of dairy cows, which is essential to maximise production performances.

Abbreviations: AIC: Akaike Information Criterion; AGR: absolute growth rate; ANAPRI: Italian Simmental Cattle Breeders Association; BCS: Body Condition Score; CFI: interval from calving to first insemination; Cint: calving interval; CV: coefficient of variation; DIM: days in milk; DO: days open; Min: minimum; Max: maximum; MSPE: mean square prediction error; MPE: mean prediction error; NIns: number of inseminations; PRI: Italian Simmental; SD: standard deviation; SCS: Somatic Cell Score; RPE: relative prediction error; r: coefficient of correlation; UC: Udder conformation; M-eq: mature-equivalent

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Introduction

Dairy herd profitability relies on the ability of productive animals to outperform in milk yield concurrently with excellent health and fertility.

However, there are other functional cow's characteristics (e.g. body conformation or body weight) which, if improved, can reduce culling rate, environmental

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impact and therefore herd profitability (Søndergaard et al. 2002; Hazel et al. 2017; Handcock et al. 2020).

Body conformation, or type, of dairy cows has been of interest to producers since the beginning of the development of breeding plans (Miglior et al. 2017). Moreover, conformation traits, including body size and muscularity, are moderately to highly heritable, and they are easy to measure in the early life of an animal (Roveglia et al. 2019). Therefore, conformation traits are included in selection indices and are used as indirect predictors of economically important traits (Abolismail et al. 2017). In the last years, genetic improvement of dairy cattle has focussed on selection of some conformation traits [e.g. body condition score (BCS) and muscularity] since these characteristics have an important role as indirect traits to improve reproductive performance (Zink et al. 2011; Frigo et al. 2013) and other functional traits such as calving ease and longevity (Chapinal et al. 2013; Sawa et al. 2013).

Italian Simmental (PRI) is a double-purpose cattle breed, mainly reared in North-eastern Italy and it is well-known for its ability to adapt to farming conditions in marginal areas (Cesarani et al. 2020b). Italian Simmental selection program considers both production and conformation traits, including muscularity, as well as functional characteristics. Genetic selection for muscularity is important to maintain and improve the dual-purpose attitude, which is positively associated with price and value of culled cows (Bazzoli et al. 2014). However, this trait could be important also from a functional point of view. Linear classification, including muscularity and BCS, is routinely recorded in all first-calving cows reared in Italy once in a lifetime. However, these characteristics are known to change within and across lactations (Dechow et al. 2004; Roche et al. 2007, 2009), and therefore, in the absence of multiple linear classification, random regression models could be employed in order to generate cow-specific muscularity and BCS along the lactation.

Therefore, the objective of the present study was to develop model to predict BCS and muscularity during the lactation of Italian Simmental dairy cows. This could be helpful to identify the most parsimonious combination of fixed and random polynomials for future genetic evaluations, and to predict muscularity and BCS at some specific lactation stages for the quantification of the association between these traits and other animal characteristics, such as survival and fertility.

Materials and methods

Data source

This study was conducted in collaboration with Italian Simmental Cattle Breeders Association (ANAPRI, Udine,

Italy), who provided conformation, fertility, and production records of 2656 Italian Simmental cows reared in 324 herds of Emilia-Romagna region, North-eastern Italy, collected between 2002 and 2020, inclusive. The data included herd of origin, cow ID, birth date, each calving date, linear classification date, parity number, and phenotypes related to conformation (including BCS and muscularity measured once in first-lactating cows), fertility [number of inseminations (NINS), days open (DO), interval calving to first insemination (CFI), and calving interval (CINT)] and production (mature equivalent 305-d milk, fat and protein yield). The muscularity was evaluated as buttock's convexity, assigning a score to cows with thighs that have an accentuated muscularity and full and muscular buttocks with clear convex profile, but with a conformation suitable to allow the udder's development. The muscularity of these areas is very important, because it allows to know the production of prime beef cuts. This measure can be assessed by trained classifiers on primiparous cows according to a linear score ranging from 1 to 9, with higher values indicating greater muscularity. These values are then converted to a linear scale ranging from 68 (thin) to 93 (muscled) points, with 1-unit increments (ANAPRI 2021).

The BCS was recorded through linear classifiers by evaluating the appearance of the ileal and ischial tuberosities, the thurl and tail head regions, the spinous and transverse process, the ilio-sacral and the ischial-coccygeal ligaments. The visual and tactile evaluation of all these areas allowed to classify cows on a five-point scale, with 0.25-unit increments according to Ferguson et al. (1994).

Statistical analysis

Obvious data errors of conformation, fertility, and production traits were set as missing. The distribution of each trait was evaluated through PROC UNIVARIATE (SAS Institute Inc., Cary, NC) and its normality was determined by both visual inspection and the Shapiro-Wilk test statistics. For traits normally distributed, phenotypic records greater than 3 standard deviations from the respective mean were excluded from the dataset. In traits, non-normally distributed records > 99th percentile of each respective trait was set as missing. Moreover, only records of BCS and muscularity measured between 5 and 365 days in milk (DIM) on cows calving between 20 and 41 months of age were retained for further analysis. The number of records after edits is reported in Table 1, while the distribution of records across DIM is provided in Figure S1.

Table 1. Descriptive statistics^a of records used for dataset.

Trait ^b	N	Mean	SD	CV, %	Min	Max
Productive traits						
Milk production M-eq ^c , kg	2647	7755.94	1833.44	23.64	1728	13,303
Fat M-eq, kg	2626	289.66	69.86	24.12	60	524
Protein M-eq, kg	2628	263.29	62.78	23.84	59	447
Fat M-eq, %	2616	3.74	0.41	10.96	2.51	5.17
Protein M-eq, %	2629	3.39	0.21	6.19	2.71	4.02
Fertility traits						
Age at calving, month	2655	29.56	4.19	14.17	20	41
DO, days	2423	130.90	78.46	59.94	21	420
NINS, units	2442	1.82	1.17	64.29	1	7
CFI, days	2340	83.06	37.64	45.32	21	200
CINT, days	2511	410.57	74.55	18.16	283	640
Linear type traits						
Frame, units	2656	81.26	3.05	3.75	68	93
Feet and legs, units	2656	80.17	3.52	4.39	68	90
Udder, units	2656	81.46	3.13	3.84	68	91
BCS, units	2539	3.50	0.29	8.29	2.25	5.00
Muscularity, units	2575	80.10	2.99	3.73	68	91

Min: minimum; Max: maximum; SD: standard deviation; CV: coefficient of variation.

^aN: number of records.

^bDO: days open; NINS: number of inseminations; CFI: interval from calving to first insemination; CINT: calving interval; UC: Udder conformation; BCS: Body Condition Score.

^cM-eq: mature-equivalent.

Pearson's correlation coefficients between BCS and muscularity to fertility and production traits were calculated using the PROC CORR (SAS Institute Inc.). Body condition score and muscularity lactation curves were developed according to the following random regression model using the software Echidna (Gilmour 2020):

$$y_{jklm} = age_j + \sum_{i=1}^n \beta_n P_n + \sum_{i=1}^n \alpha_{nk} P_{nk} + herd_{yearl} + e_{jklm},$$

where y_{jklm} is the BCS or muscularity measured by linear classifier for the k th animal, age_j is the fixed effect of the j th age at linear scoring (30 classes), β_n is the n th (1–4) fixed regression coefficient of the Legendre polynomial modelling all records of muscularity or BCS throughout the lactation, α_{nk} is the n th (1–4) random regression coefficient of the Legendre polynomial modelling records of muscularity or BCS throughout the lactation for cow k th (2575 classes), $herd_{yearl}$ is the random effect of the l th herd-year of linear classification (937 classes), and e_{jklm} is the random residual term. Coefficients of the Legendre polynomial at each DIM were calculated as follows (Kirkpatrick et al. 1990):

$$P_0 = \sqrt{\frac{1}{2}}$$

$$P_1 = z\sqrt{\frac{3}{2}}$$

$$P_2 = \left[\left(\frac{3}{2} \right) z^2 - \left(\frac{1}{2} \right) \right] \sqrt{\frac{5}{2}}$$

$$P_3 = \sqrt{\frac{7}{2}} \left(\frac{5}{2} z^3 - \sqrt{\frac{3}{2}} z \right)$$

$$P_4 = \sqrt{\frac{9}{2}} \left(\frac{35}{8} z^4 - \frac{30}{8} z^2 + \frac{3}{8} \right)$$

$$P_5 = \sqrt{\frac{11}{2}} \left(\frac{63}{8} z^5 - \frac{70}{8} z^3 + \frac{15}{8} z \right)$$

where z is the standardised DIM, calculated as $z = \frac{2(DIM - DIM_{min})}{(DIM_{max} - DIM_{min})} - 1$ and DIM_{min} and DIM_{max} are the minimum and maximum DIM, respectively (Li et al. 2020).

Different orders of fixed and random Legendre polynomial were fitted to select the most parsimonious combination to model both BCS and muscularity lactation curves. In the first instance, only a first-order Legendre polynomial was fitted as fixed effect. Second, a first-order Legendre polynomial was fitted also to the random cow effect. Third, a second-order Legendre polynomial was included as fixed effect followed by a first and subsequently second-order polynomial on the random cow effect. In the other models, the order of Legendre polynomial was increased by one unit firstly as a fixed effect, followed by a one unit increase of the random Legendre polynomial order. The most parsimonious fixed Legendre polynomial order was chosen based on visual inspection of the resulting lactation profile for both BCS and muscularity. According to O'Neill et al. (2013), the criteria to select the most parsimonious order of the random Legendre polynomial were: (i) the coefficient of

correlation (r) between actual and predicted BCS and muscularity; (ii) the Mean Square Prediction Error (MSPE); (iii) the Mean Prediction Error (MPE); (iv) the Relative Prediction Error (RPE); and (v) the Akaike Information Criterion (AIC).

Based on Bibby and Toutenburg (1977), the MSPE is the sum three components, namely, the mean bias, line bias and random variation. These are represented in the following equation:

$$MSPE = (x_m - \hat{x}_m)^2 + S_x^2(1 - b)^2 + S_x^2(1 - r^2)$$

where x_m and \hat{x}_m are the means of the actual and predicted BCS and muscularity, respectively; S_x^2 and S_x^2 are the variances of the actual and predicted BCS and muscularity, respectively; b is the slope of the actual regression (x) on predicted (\hat{x}) and r^2 is the coefficient of determination of x and \hat{x} .

MPE and RPE were calculated as follows:

$$MPE = \sqrt{MSPE}$$

$$RPE (\%) = \left(\frac{MPE}{A_m} \right) 100$$

Solutions of the most parsimonious model for muscularity and BCS were used to generate individual random lactation curves for both traits. This dataset, which included a total of 939,875 predictions of muscularity and BCS (i.e. 365 predictions for individual DIM for each individual cow), was then stratified into four classes based on cows' age at calving as: 20–26 months (early calving cows), 27–29 months (mid-early calving cows), 30–32 months (mid-late calving cows), and 33–41 months (late calving cows). Subsequently a linear mixed model, adjusting for the fixed effect of the interaction between individual DIM and age at calving class, was employed to generate average lactation profile of muscularity and BCS for the different age at calving classes.

Finally, the absolute muscularity and BCS growth rate (AGR) was calculated as:

$$AGR = \frac{(BT_x - BT_y)}{(t_x - t_y)}$$

where BT_x and BT_y are the corresponding predicted muscularity or BCS at DIM x and y , t_x is the initial age in days and t_y is the final cow's age in days.

Results and discussion

Descriptive statistics

Summary statistics for conformation, fertility, and production traits are reported in Table 1. Mature-equivalent (M-eq) 305-d milk production averaged

7755.94 ± 1833.44 kg, while mean values for M-eq 305-d fat and protein yields were 289.66 and 263.29 kg, respectively (Table 1). The average daily milk yield is slightly greater than results reported by Penasa et al. (2014) and Visentin et al. (2018), who investigated sources of variation of milk quality characteristics in Simmental and other dual-purpose and specialised dairy cows in Veneto Region and Bolzano Province (Italy), respectively. This is also reflected in lower average fat and protein percentage reported in the present study, compared to Penasa et al. (2014) and Visentin et al. (2018). The age at first calving of the cows involved in the present study was on average 29.56 ± 4.19 months. The means of CFI, DO, CINT were 83.06, 130.90, and 410.57 days, respectively (Table 1). The average value of CINT is similar to the value of 400 d reported by Cesarani et al. (2020a) in a large dataset of Italian Simmental cows. The average BCS of cows involved in the current study was 3.50 and ranged from 2.25 to 5.00, similarly to Frigo et al. (2013) who estimated genetic parameters of BCS and muscularity in Italian Simmental. Kadarmideen and Wegmann (2003) reported lower BCS values in Swiss Holstein compared with the values estimated in the present study. These results suggest that Italian Simmental is generally less prone to a reduction of BCS, and therefore subcutaneous adipose tissue, through lactation. Among all traits considered in the present study, linear traits were those characterised by the lowest variation (CV ranging from 3.73% to 8.29%; Table 1). The coefficient of variation of BCS recorded in this study is similar to that reported in Roche et al. (2009). The average muscularity score of cows in the present study was 80.10 ± 2.99 units, whereby the coefficient of variation was the smallest among all linear traits (3.73%; Table 1). This result is slightly greater, yet expected, than the CV reported by Cesarani et al. (2020b) who estimated genetic parameters of beef traits, including muscularity, in Italian Simmental using data collected on young bulls.

Phenotypic correlations

Table 2 shows the correlation coefficients of muscularity and BCS between other conformation, fertility and reproduction traits. As regards the productive traits, results indicated a positive and significant correlation between mature-equivalent productive traits and muscularity (from 0.04 to 0.20, $p < .05$). While the analysis' result showed a positive and statistically significant ($p < .05$) correlation between BCS, Fat M-eq %, and Protein M-eq % (0.04 and 0.21, respectively), the

Table 2. Pearson correlation coefficients between BCS and muscularity and other productive, fertility, and linear type traits.

Trait ^a	Muscularity	BCS
Productive traits		
Milk production M-eq ^b , kg	0.04*	-0.02
Fat M-eq, kg	0.06**	-0.002
Protein M-eq, kg	0.09**	0.04
Fat M-eq, %	0.04*	0.04*
Protein M-eq, %	0.20**	0.21**
Fertility traits		
Age at calving, month	0.02	0.02
DO, days	-0.01	-0.01
NINS, units	0.05**	0.05*
CFI, days	-0.03	-0.03
CINT, days	0.01	0.02
Linear type traits		
Frame, units	0.30**	0.14**
Feet and legs, units	0.13**	0.15**
Udder, units	-0.04	-0.06**
BCS, units	0.59**	-

* $p < .05$; ** $p < .01$.^aDO: days open; NIns: number of inseminations; CFI: interval from calving to first insemination; CInt: calving interval; UC: Udder conformation; BCS: Body Condition Score^bM-eq: mature-equivalent.

association between muscularity and BCS to milk production traits is known to depend on dairy cattle breeds. In particular, De Haas et al. (2007b) suggested that in Holstein and Simmental breeds, body measurements and milk production traits were strongly and positively genetically correlated. This indicates that in these dairy breeds, genetically taller, wider and deeper cows are more productive. Some studies (Mazza et al. 2016; Mancin et al. 2021) reported a positive correlation between udder conformation traits and muscularity. Mazza et al. (2016), using factor analysis to individual type traits for muscularity and udder of 32,275 first parity Aosta Red Pied cows, obtained a negative genetic correlation with both muscularity and udder size (-0.38). Comparable correlations between muscularity and udder size have also been reported in other specialised dairy and beef cattle. For example, Mrode and Swanson (1994) observed a negative correlation in Ayrshire (from -0.41 to -0.12). Also, Mantovani et al. (2010) reported a negative correlation in Italian Piemontese beef cattle (from -0.19 to -0.15). However, Mazza et al. (2016) reported a positive but weak genetic correlation between muscularity and udder conformation (0.21). The results obtained in the present study reflect the correlation estimated by Sartori et al. (2015), in Aostan Chestnut and in other dairy specialised (e.g. Brown Swiss; De Haas et al. 2007a, 2007b) or dual-purpose breeds such as Simmental (Frigo et al. 2013) or Rendena (Mazza 2015). Also, Mancin et al. (2021), through factor analysis of 21 type traits evaluation (including rear muscularity) of 11,320 Alpine Grey primiparous cows,

reported a negative correlation between milk traits (in particular the udder volume) and rear muscularity (-0.28). Furthermore, Mancin et al. (2021) have observed that head traits and the rear legs traits are negatively correlated with beef traits (-0.32 with rear muscularity). All these results provided some examples of the antagonism between beef and dairy attitudes; Royal et al. (2002) have described this phenomenon as a result of the gluconeogenesis occurring during milk production, involving the mobilisation of energy from tissues and from both protein and fat reserves. The negative correlations reported between milk and beef traits can be associated in the distinct asset of genes involved in metabolism regulation, collagen catabolism's and myogenesis compared to milk synthesis (Maiorano et al. 2018).

The present study found a positive correlation between muscularity and number of inseminations (0.05, $p < .01$). A similar trend was observed with the correlation between cows' BCS and number of inseminations (0.05, $p < .05$). Berry et al. (2003) and De Haas et al. (2007a) estimated the genetic correlations between BCS and fertility traits with a random regression model, suggesting that BCS is an indicator of cow's fertility independently from the frequency of scoring.

As far as it concerns the linear type traits, data of the present research reported a strong positive correlation between muscularity and some conformation traits (0.30, 0.13 and 0.59, for Frame, Feet and legs and BCS, respectively, $p < .01$), while BCS has a positive correlation between frame (0.14, $p < .01$), feet and legs (0.15, $p < .01$) but a negative correlation to udder (-0.06, $p < .01$). Regarding Holstein, De Haas et al. (2007b) reported a weak genetic correlation between body conformation (e.g. body depth and muscularity) and SCS. These correlations indicate that Brown Swiss and Simmental cows with a body conformation more 'dairy type' (i.e. with larger size and less muscularity) have higher SCS and therefore potentially more udder health problems. However, Mancin et al. (2021) observed that in first-calving Alpine Grey, muscularity had a moderate negative relationship with milk yield traits (from -0.16 to -0.46).

Goodness of fit statistics

Tables 3 and 4 present the goodness of fit statistics of the prediction models for muscularity and BCS, respectively. Regarding muscularity, the most parsimonious model with the lowest AIC (7964.40), was obtained for the regression model applying a cubic

Table 3. Goodness of fit measures^a of Legendre polynomials of different orders for the prediction of muscularity of Italian Simmental in Emilia Romagna dairy herds.

Polynomial order		Regression									
Fixed	Random	Mean _A	Mean _P	Bias	Intercept	Slope	<i>r</i>	MSPE	MPE	RPE	AIC
1	1	80.10	80.10	0.00	45.29	0.43	0.87	2.75	1.66	2.07	7975.10
2	1	80.10	80.10	0.00	45.21	0.44	0.87	2.75	1.66	2.07	7979.49
3	1	80.10	80.10	0.00	46.68	0.42	0.85	2.83	1.68	2.10	7964.40
4	1	80.10	80.10	0.00	46.73	0.42	0.85	2.83	1.68	2.10	7968.36
2	2	80.10	80.10	0.00	48.04	0.40	0.84	2.65	1.63	2.03	7982.01
3	2	80.10	80.10	0.00	50.02	0.38	0.81	2.74	1.65	2.07	7966.95
4	2	80.10	80.10	0.00	50.01	0.38	0.81	2.74	1.66	2.07	7970.86
3	3	80.10	80.10	0.00	51.87	0.35	0.78	2.70	1.64	2.05	7968.05
4	3	80.10	80.10	0.00	51.85	0.35	0.78	2.71	1.65	2.05	7971.93
4	4	80.10	80.10	0.00	53.41	0.33	0.75	2.69	1.64	2.05	7972.60

^aMean_A: mean of actual values; Mean_P: mean of predicted values; *r*: coefficient of correlation; MSPE: mean square prediction error; MPE: mean prediction error; RPE: relative prediction error; AIC: Akaike information criterion.

Table 4. Goodness of fit measures^a of Legendre polynomials of different orders for the prediction of BCS of Italian Simmental in Emilia Romagna dairy herds.

Polynomial order		Regression									
Fixed	Random	Mean _A	Mean _P	Bias	Intercept	Slope	<i>R</i>	MSPE	MPE	RPE	AIC
1	1	3.50	3.50	0.00	2.06	0.41	0.84	0.00	0.02	0.45	-3929.97
2	1	3.50	3.50	0.00	2.07	0.41	0.84	0.00	0.02	0.45	-3922.12
3	1	3.50	3.50	0.00	2.10	0.40	0.82	0.00	0.02	0.46	-3920.42
4	1	3.50	3.50	0.00	2.09	0.40	0.83	0.00	0.02	0.46	-3912.83
2	2	3.50	3.50	0.00	2.29	0.35	0.76	0.00	0.02	0.45	-3919.38
3	2	3.50	3.50	0.00	2.30	0.34	0.75	0.00	0.02	0.45	-3918.06
4	2	3.50	3.50	0.00	2.29	0.35	0.75	0.00	0.02	0.45	-3910.48
3	3	3.50	3.50	0.00	2.12	0.39	0.82	0.00	0.02	0.45	-3920.89
4	3	3.50	3.50	0.00	2.11	0.40	0.82	0.00	0.02	0.46	-3913.49
4	4	3.50	3.50	0.00	2.11	0.40	0.82	0.00	0.02	0.46	-3913.43

^aMean_A: mean of actual values; Mean_P: mean of predicted values; *r*: coefficient of correlation; MSPE: mean square prediction error; MPE: mean prediction error; RPE: relative prediction error; AIC: Akaike information criterion.

fixed polynomial and a linear random polynomial (Table 3). The AIC (Akaike 1974) is useful for model comparison to select the most parsimonious model which minimises information loss (i.e. the model with the lowest AIC). In addition, in this prediction model, the slope of the linear regression between measured and predicted muscularity was 0.42, with a strong correlation coefficient (0.85; Table 3) while RPE was 2.10. Models with a lower order fixed polynomial were characterised by similar correlation coefficients between actual and predicted values of muscularity (i.e. 0.87; Table 3), slope (i.e. 0.42–0.43; Table 3), yet by greater AIC compared. Regarding BCS, the model with the smallest AIC was the model that included a fourth-order fixed polynomial and a random linear polynomial. However, based on the lactation profile of BCS, the third-order fixed polynomial was the most parsimonious to model BCS. In particular, the AIC of the model fitting a cubic fixed polynomial and a linear random polynomial was -3920.42 and this combination was considered the most parsimonious also to model BCS. The correlation coefficients between actual and predicted BCS by the latter model was strong

(0.82; Table 4) with a small RPE (0.46; Table 4). According to Fuentes-Pila et al. (1996), a RPE value lower than 10% indicated satisfactory prediction, between 10% and 20% indicates good or acceptable prediction, and greater than 20% indicates unsatisfactory prediction. In the present study, the RPE obtained for all the models was excellent.

Muscularity and BCS modelling

Figure 1 shows the average random lactation curves profiles for muscularity (A) and BCS (B) of cows at different calving age (in months). Both profiles indicated a nadir around the period corresponding to milk production peak. These results are consistent also with studies conducted in Italian Simmental (Frigo et al. 2013) or in Holstein-Friesian (Megahed et al. 2019). During this period, cows usually have strong nutrient requirements which cannot be fully compensated with feed intake (Harder et al. 2019). Muscularity of heifers and dairy cows constitute a protein and energy reserve that is used in challenging periods, allowing the animal to avoid the mobilisation, in very short

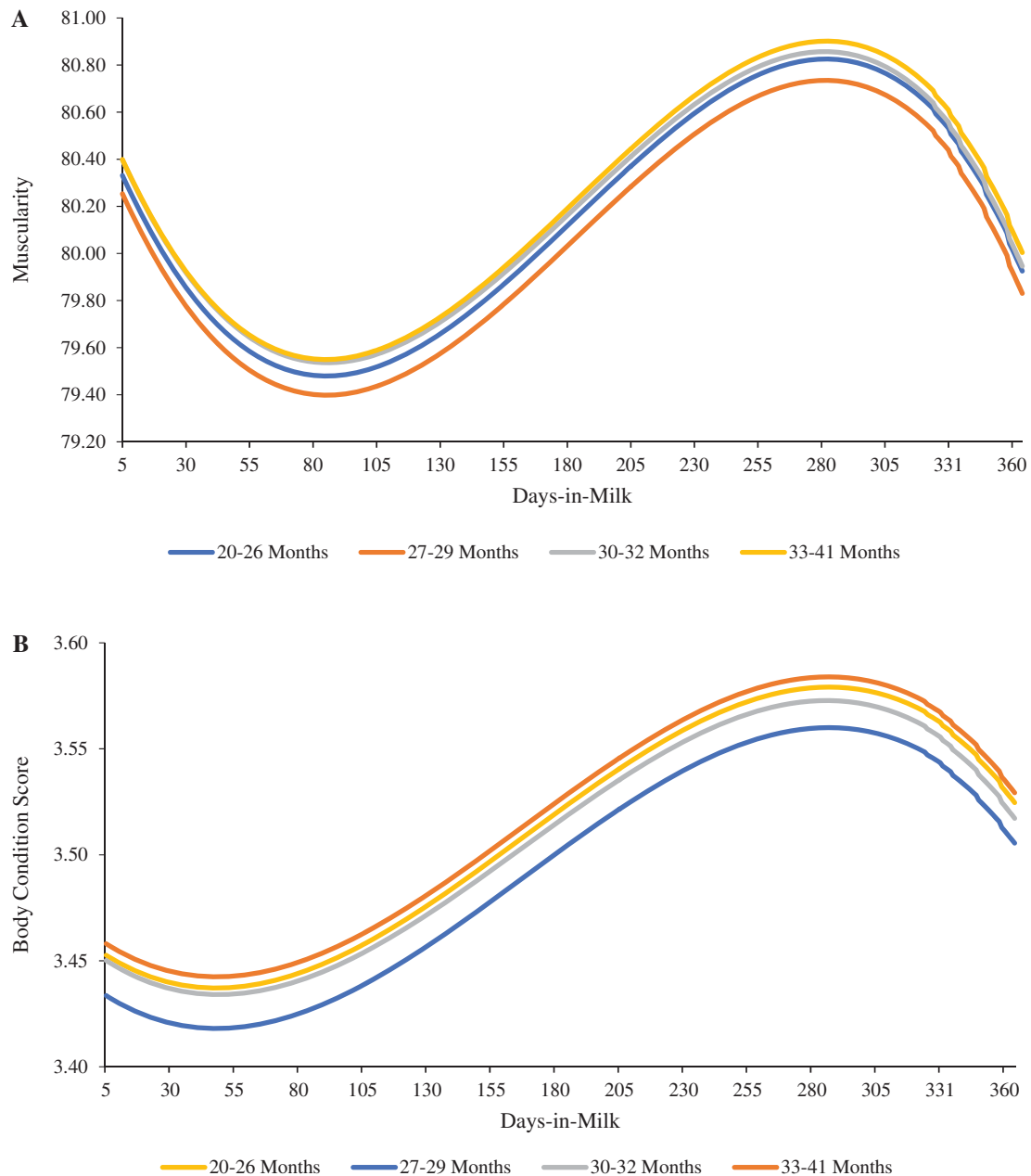


Figure 1. Lactation curve profiles for muscularity (A) or Body Condition Score (B) for cows calving at different age (in months).

periods, of all fat reserves, determining the appearance of typical symptoms known as fat cow syndrome (Roche et al. 2013; McNamara and Huber 2018; Pascottini et al. 2020). This state of negative energy balance affects the cow's body reserves making a loss of body tissue to compensate the energy loss; indeed, this problem can make cows more susceptible to some diseases (such as mastitis or lameness) or metabolic disorders (e.g. acidosis or ketosis) and affect the reproductive performance (von Leesen et al. 2014). The muscle tissue's mobilisation contributes to free amino acids in the plasma pool, which can be used for numerous biological processes including milk

protein synthesis, direct oxidation or gluconeogenesis (McCabe and Boerman 2020). This situation is also reported by other authors (Roche et al. 2013; Pascottini et al. 2020) and is a consequence of genetic selection (especially in some breeds, e.g. Holstein Friesian) mostly focussed on prioritising milk production. However, after this period (Figure 1), on average, cow's muscularity recovered up to pre-lactation levels.

Figure 2 shows the AGR variations of muscularity (A) and BCS (B). Figure 2(A) indicates that the period of muscularity growth within lactation is approximately between 82 and 277 DIM. As regards to BCS (Figure 2(B)), the AGR shows an earlier recovery of

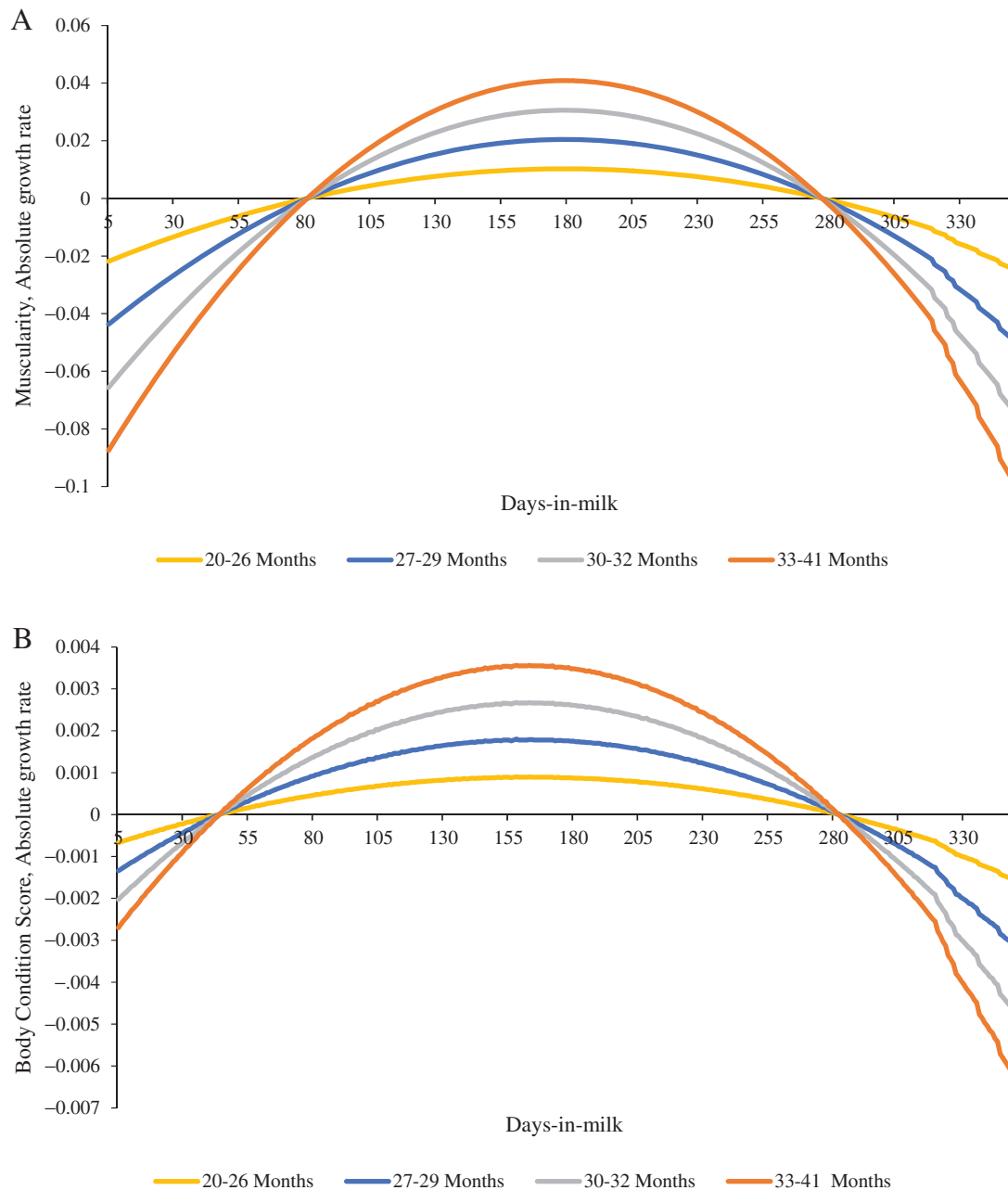


Figure 2. Absolute growth rate (AGR) for muscularity (A) and body condition score (BCS) (B) for cows calving at different age (in months).

body fat reserves starting before the second month of lactation, with a continuous positive trend until the ninth month of lactation. These trends are similar to that reported in other studies (Berry et al. 2006; McCarthy et al. 2007; Sumner and McNamara 2007). As stated previously, this moment corresponds to the period when the animal has a greater nutritional need, necessary to sustain milk production, maintenance requirements and foetal growth. In fact, the nutritional needs of foetus have the priority over many metabolic functions of the mother. The mobilisation of muscle proteins occurring in this phase are

therefore also involved in animals' reproductive performances. The use of cow's protein reserve is of crucial importance in double-purpose breeds (therefore also in Italian Simmental) that include meat production in their breeding objectives, supporting the inclusion of muscularity evaluation during linear type classification. Frigo et al. (2013) observed a decrease of muscularity in early lactation in Italian Simmental in comparison to high milk producing cows. This characteristic is different in various cattle breeds. Indeed, Tamminga et al. (1997) have observed that in Dutch and Holstein Friesian cows the mobilisation of body

reserves, and the relative composition of tissues involved, were different over the lactation.

The use of random regression models to generate cow-specific lactation profile of muscularity and BCS could be important for different purposes. In the first instance, random regressions are normally used nowadays to generate EBV for milk traits across DIM within the national genetic evaluations. This estimation could be useful in order to alter not only the height of a lactation profile for a specific trait, which could be indeed achieved by a simple repeatability animal model, but also its shape (Kirkpatrick et al. 1990). This is of particular interest, for instance, in traits manifesting a significant variation within lactation stage, such as production traits (Jensen 2001), processing characteristics (Visentin et al. 2017), but also other animal characteristics such as BCS and fertility (Berry et al. 2003; De Haas et al. 2007a). Moreover, the possibility to generate cow-specific lactation profiles for muscularity and BCS could be important for management purposes and to quantify the association between these traits at some specific lactation stages and cows' survival rate or fertility. Another outcome of the present study is the identification of the most parsimonious orders of fixed and random Legendre polynomials for future genetic evaluations using random regression models. However, to increase the accuracy of prediction of both muscularity and BCS more measurements per lactation are needed, even using technologies in the field of precision livestock farming.

Conclusions

Results reported in this study indicate that random regression using Legendre polynomials can accurately predict muscularity and BCS of Italian Simmental dairy cows. The differences observed during the lactating period are due to the increase of nutritional requirements of cows, especially during the lactation peak that are not met by the intake of nutrients. During the last lactation stage, dairy cows mobilise fat reserve and muscle's protein to supply amino acids for gluconeogenesis and for milk protein synthesis. Results of the present study can be exploited in order to quantify the association between conformation and (re)productive traits at different period of lactation, in the absence of a regular and repeated measures of muscularity and BCS within lactation.

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Ethical approval

This study did not require manipulation or modification of the usual handling of the animals, since we have worked directly with the routine records provided by the breeders' associations.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

Data used in the current study are available upon request from the corresponding author.

References

- Abo-Ismael MK, Brito LF, Miller SP, Sargolzaei M, Grossi DA, Moore SS, Plastow G, Stothard P, Nayeri S, Schenkel FS. 2017. Genome-wide association studies and genomic prediction of breeding values for calving performance and body conformation traits in Holstein cattle. *Genet Sel E*. 49:82.
- Akaike H. 1974. A new look at the statistical model identification. *IEEE Trans Automat Contr*. 19(6):716–723.
- Associazione Nazionale Allevatori Pezzata Rossa Italiana (ANAPRI). 2021. La descrizione e la valutazione morfologica dei bovini, statistica, principi di genetica, descrizione lineare, valutazioni
- Bazzoli I, De Marchi M, Cecchinato A, Berry DP, Bittante G. 2014. Factors associated with age at slaughter and carcass weight, price, and value of dairy cull cows. *J Dairy Sci*. 97(2):1082–1091
- Berry DP, Buckley F, Dillon P, Evans RD, Rath M, Veerkamp RF. 2003. Genetic relationships among body condition score, body weight, milk yield, and fertility in dairy cows. *J Dairy Sci*. 86(6):2193–2204.
- Berry DP, Macdonald KA, Penno JW, Roche JR. 2006. Association between body condition score and live weight in pasture-based Holstein–Friesian dairy cows. *J Dairy Res*. 73(4):487–491.
- Bibby J, Toutenburg H. 1977. Prediction and improved estimation in linear models. London: Wiley.
- Cesarani A, Gaspa G, Masuda Y, Degano L, Vicario D, Lourenco DAL, Macciotta NPP. 2020a. Variance components using genomic information for 2 functional traits in Italian Simmental cattle: calving interval and lactation persistency. *J Dairy Sci*. 103(6):5227–5233.

- Cesarani A, Hidalgo J, Garcia A, Degano L, Vicario D, Masuda Y, Misztal I, Lourenco D. 2020b. Beef trait genetic parameters based on old and recent data and its implications for genomic predictions in Italian Simmental cattle. *J Anim Sci.* 98:skaa242.
- Chapinal N, Koeck A, Sewalem A, Kelton DF, Mason S, Cramer G, Miglior F. 2013. Genetic parameters for hoof lesions and their relationship with feet and leg traits in Canadian Holstein cows. *J Dairy Sci.* 96(4):2596–2604.
- De Haas Y, Janss LLG, Kadarmideen HN. 2007a. Genetic correlations between body condition scores and fertility in dairy cattle using bivariate random regression models. *J Anim Breed Genet.* 124(5):277–285.
- De Haas Y, Janss LLG, Kadarmideen HN. 2007b. Genetic and phenotypic parameters for conformation and yield traits in three Swiss dairy cattle breeds. *J Anim Breed Genet.* 124(1):12–19.
- Dechow CD, Rogers GW, Klei L, Lawlor TJ. 2004. Heritability and correlations for body condition score and dairy farm within and across lactation and age. *J Dairy Sci.* 87(3):717–728.
- Ferguson JD, Galligan DT, Thomsen N. 1994. Principal descriptors of body condition score in Holstein cows. *J Dairy Sci.* 77(9):2695–2703.
- Frigo E, Samorè AB, Vicario D, Bagnato A, Pedron O. 2013. Heritabilities and genetic correlations of body condition score and muscularity with productive traits and their trend functions in Italian Simmental Cattle. *Ital J Anim Sci.* 12(2):e40.
- Fuentes-Pila J, DeLorenzo MA, Beede DK, Staples CR, Holter JB. 1996. Evaluation of equations based on animal factors to predict intake of lactating Holstein cows. *J Dairy Sci.* 79(9):1562–1571.
- Gilmour AR. 2020. Echidna mixed model software. www.EchidnaMMS.org.
- Handcock RC, Lopez-Villalobos N, McNaughton LR, Back PJ, Edwards GR, Hickson RE. 2020. Body weight of dairy heifers is positively associated with reproduction and stayability. *J Dairy Sci.* 103(5):4466–4474.
- Harder I, Stamer E, Junge W, Thaller G. 2019. Lactation curves and model evaluation for feed intake and energy balance in dairy cows. *J Dairy Sci.* 102(8):7204–7216.
- Hazel AR, Heins BJ and Hansen LB. 2017. Fertility, survival, and conformation of Montbéliarde × Holstein and Viking Red × Holstein crossbred cows compared with pure Holstein cows during first lactation in 8 commercial dairy herds. *Journal of Dairy Science*, 100(11), 9447–9458.
- Italian Breeder Association (AIA). 2020. Metadata (accessed 2021 Jul 23). <http://bollettino.aia.it/>.
- Italian Simmental Cattle Breeders Association (ANAPRI). 2017. Metadata (accessed 2021 Jul 15) <http://www.anapri.it> (accessed 7.15.21).
- Jensen J. 2001. Genetic evaluation of dairy cattle using test-day models. *J Dairy Sci.* 84(12):2803–2812.
- Kadarmideen HN, Wegmann S. 2003. Genetic parameters for body condition score and its relationship with type and production traits in Swiss Holsteins. *J Dairy Sci.* 86(11):3685–3693.
- Kirkpatrick M, Lofsvold D, Bulmer M. 1990. Analysis of the inheritance, selection and evolution of growth trajectories. *Genetics.* 124(4):979–993.
- Li J, Gao H, Madsen P, Li R, Liu W, Bao P, Xue G, Gao Y, Di X, Su G. 2020. Impact of the order of Legendre polynomials in random regression model on genetic evaluation for milk yield in dairy cattle population. *Front Genet.* 11:586155.
- Maiorano AM, Lourenco DL, Tsuruta S, Ospina AMT, Stafuzza NB, Masuda Y, Filho AEV, Cyrillo J. d S, Curi RA, Silva J. d V. 2018. Assessing genetic architecture and signatures of selection of dual purpose Gir cattle populations using genomic information. *PLOS One.* 13(8):e0200694.
- Mancin E, Sartori C, Guzzo N, Tuliozi B, Mantovani R. 2021. Selection response due to different combination of antagonistic milk, beef, and morphological traits in the Alpine Grey cattle breed. *Animals.* 11(5):1340.
- Mantovani R, Cassandro M, Contiero B, Albera A, Bittante G. 2010. Genetic evaluation of type traits in hypertrophic Piemontese cows. *J Anim Sci.* 88(11):3504–3512.
- Mazza S. 2015. Genetics of linear type traits in local dual-purpose breeds and relationships with productive traits [PhD Thesis]. University of Padova.
- Mazza S, Guzzo N, Sartori C, Mantovani R. 2016. Genetic correlations between type and test-day milk yield in small dual-purpose cattle populations: the Aosta Red Pied breed as a case study. *J Dairy Sci.* 99(10):8127–8136.
- McCabe CJ, Boerman JP. 2020. Invited review: Quantifying protein mobilization in dairy cows during the transition period. *Appl Anim Sci.* 36(3):389–396.
- McCarthy S, Berry DP, Dillon P, Rath M, Horan B. 2007. Influence of Holstein-Friesian strain and feed system on body weight and body condition score lactation profiles. *J Dairy Sci.* 90(4):1859–1869.
- McNamara JP, Huber K. 2018. Metabolic and endocrine role of adipose tissue during lactation. *Annu Rev Anim Biosci.* 6:177–195.
- Megahed AA, Hiew MWH, Ragland D, Constable PD. 2019. Changes in skeletal muscle thickness and echogenicity and plasma creatinine concentration as indicators of protein and intramuscular fat mobilization in periparturient dairy cows. *J Dairy Sci.* 102(6):5550–5565.
- Miglior F, Fleming A, Malchiodi F, Brito LF, Martin P, Baes CF. 2017. A 100-year review: identification and genetic selection of economically important traits in dairy cattle. *J Dairy Sci.* 100(12):10251–10271.
- Mrode RA, Swanson GJT. 1994. Genetic and phenotypic relationships between conformation and production traits in Ayrshire heifers. *Anim Sci.* 58(3):335–338.
- O'Neill BF, Lewis E, O'Donovan M, Shalloo L, Mulligan FJ, Boland TM, Delagarde R. 2013. Evaluation of the Grazeln model of grass dry-matter intake and milk production prediction for dairy cows in temperate grass-based production systems. 1–Sward characteristics and grazing management factors. *Grass Forage Sci.* 68(4):504–523.
- Pascottini OB, Leroy JLMR, Opsomer G. 2020. Metabolic stress in the transition period of dairy cows: focusing on the prepartum period. *Animals.* 10(8):1419.
- Penasa M, Tiezzi F, Sturaro A, Cassandro M, De Marchi M. 2014. A comparison of the predicted coagulation characteristics and composition of milk from multi-breed herds of Holstein-Friesian, Brown Swiss and Simmental cows. *Int Dairy J.* 35(1):6–10.
- Roche JR, Friggens NC, Kay JK, Fisher MW, Stafford KJ, Berry DP. 2009. Invited review: body condition score and its

- association with dairy cow productivity, health, and welfare. *J Dairy Sci.* 92(12):5769–5801.
- Roche JR, Kay JK, Friggens NC, Loor JJ, Berry DP. 2013. Assessing and managing body condition score for the prevention of metabolic disease in dairy cows. *Vet Clin North Am Food Anim Pract.* 29(2):323–336.
- Roche JR, Lee JM, Macdonald KA, Berry DP. 2007. Relationships among body condition score, body weight, and milk production variables in pasture-based dairy cows. *J Dairy Sci.* 90(8):3802–3815.
- Roveglia C, Niero G, Bobbo T, Penasa M, Finocchiaro R, Visentin G, Lopez-Villalobos N, Cassandro M. 2019. Genetic parameters for linear type traits including locomotion in Italian Jersey cattle breed. *Livest Sci.* 229:131–136.
- Royal MD, Pryce JE, Woolliams JA, Flint APF. 2002. The genetic relationship between commencement of luteal activity and calving interval, body condition score, production, and linear type traits in Holstein-Friesian dairy cattle. *J Dairy Sci.* 85(11):3071–3080.
- Sartori C, Mazza S, Guzzo N, Mantovani R. 2015. Evolution of increased competitiveness in cows trades off with reduced milk yield, fertility and more masculine morphology. *Evolution.* 69(8):2235–2245.
- Sawa A, Bogucki M, Krężel-Czopek S, Neja W. 2013. Relationship between conformation traits and lifetime production efficiency of cows. *ISRN Vet Sci.* 2013:124690.
- Søndergaard E, Sørensen MK, Mao IL, Jensen J. 2002. Genetic parameters of production, feed intake, body weight, body composition, and udder health in lactating dairy cows. *Livest Prod Sci.* 77(1):23–34.
- Sumner JM, McNamara JP. 2007. Expression of lipolytic genes in the adipose tissue of pregnant and lactating Holstein dairy cattle. *J Dairy Sci.* 90(11):5237–5246.
- Tamminga S, Luteijn PA, Meijer RGM. 1997. Changes in composition and energy content of liveweight loss in dairy cows with time after parturition. *Livest Prod Sci.* 52(1):31–38.
- Visentin G, McParland S, De Marchi M, McDermott A, Fenelon MA, Penasa M, Berry DP. 2017. Processing characteristics of dairy cow milk are moderately heritable. *J Dairy Sci.* 100(8):6343–6355.
- Visentin G, Penasa M, Niero G, Cassandro M, Marchi MD. 2018. Phenotypic characterisation of major mineral composition predicted by mid-infrared spectroscopy in cow milk. *Ital J Anim Sci.* 17(3):549–556.
- von Leesen R, Tetens J, Stamer E, Junge W, Thaller G, Krattenmacher N. 2014. Effect of genetic merit for energy balance on luteal activity and subsequent reproductive performance in primiparous Holstein-Friesian cows. *J Dairy Sci.* 97(2):1128–1138.
- Zink V, Štípková M, Lassen J. 2011. Genetic parameters for female fertility, locomotion, body condition score, and linear type traits in Czech Holstein cattle. *J Dairy Sci.* 94(10):5176–5182.