PAPER

Heritabilities and genetic correlations of body condition score and muscularity with productive traits and their trend functions in Italian Simmental cattle

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Abstract

With the aim to study the genetics of energy and muscle balance in the Italian Simmental breed, the objectives of this study were: i) the estimation of the genetic parameters for body condition score (BCS) and muscularity (MU) score; ii) the estimation of genetic correlations of BCS and MU with productive traits; iii) the estimation of the expected patterns of BCS and MU over lactation. A total of 47,839 records of first-parity lactating cows, collected from 1999 to 2007 in 2794 herds, were used. Two-trait animal models were analyzed using restricted maximum likelihood (REML) procedures to estimate (co)variance components. The expected patterns of BCS and MU along the lactation of first parity cows were estimated from the solutions of DIM fixed effect obtained from an univariate mixed model for both the traits. The heritability estimated was 0.18 for BCS, 0.38 for MU, and ranged from 0.13 to 0.18 for yield traits. The genetic correlations between BCS, MU and yield traits were negative (-0.17 to -0.63). The genetic correlation between BCS and MU was strongly positive (0.88), indicating that cows that genetically tend to have high BCS are more likely to have high values of MU. The genetic parameters estimated suggested that selection for BCS and MU in dual purpose breeds may be possible, and BCS may indirectly improve MU. The expected patterns for BCS and MU showed the trend of these two traits along the lactation and can help farmers in planning the best management of the lactating cows.

Introduction

Body condition score (BCS) assesses the energy reserves of dairy cows and is therefore commonly used as an indicator of the extent and the duration of the negative energy balance (Roche et al., 2009) in early lactation, period in which the feed intake is not sufficient to meet energy requirements of milk production (Banos et al., 2005; Chebel et al., 2008). Many studies reported a moderate heritability of BCS (from 0.25 to 0.35) in dairy breeds (Berry et al., 2002; Pryce and Harris, 2006; Dal Zotto et al., 2007). The interest for BCS has increased in recent years for its important role as indirect trait to improve the reproductive performances and the robustness of dairy cows (Pryce et al., 2000; Kadarmideen and Wegmann, 2003; Zink et al., 2011). At the genetic level, milk, fat, and protein yields have been shown to be correlated with BCS loss in early lactation (Berry et al., 2002; Dechow et al., 2002), and the selection for higher milk production is associated to higher mobilization of body reserves (Agnew and Yan, 2000; Coffey et al., 2004). Dechow et al. (2002) suggested that genetic selection should aim to increase milk yield without increasing the amount of BCS loss during early lactation, which would result in an efficient dairy production and an improved health status of animals.

Lactating cows can also use protein reserve for milk production during early lactation, to meet increased energy demand and/or to supply specific amino acids for milk protein synthesis and hepatic gluconeogenesis (Odwongo, 1984, Chibisa et al., 2008). Associated with protein mobilization are such factors as nutrition, hormonal balance, sex and genetic constitution, which influence the protein components of animal tissue. Even if body fat reserves are recognized as the major source of energy reserves, the catabolism of protein may also contribute to nutrient requirements in early lactation (Chibisa et al., 2008). In this period, body fat mobilization ranges from 41 to 90 kg (Erdman and Andrew, 1989) and protein mobilization ranges from 21 to 24 kg (Komaragiri et al., 1998). Therefore, in addition to the negative energy balance, cows are in a negative nitrogen balance in early lactation (Plaizer et al., 2000). Phillips et al. (2003) have suggested that the breakdown of muscle protein to provide amino acids for production of milk protein is a mechanism of the normal metabolic adaptation to the high nutrient demand typical of the early lactation. Moreover there can be a redistribution of protein away from carcass toward tissues that support lactation, i.e., gastro intestinal tract and mammary

gland (Andrew et al., 1994). Muscular tissue is more abundant in dual purpose breeds than in dairy breeds. The Italian Simmental is a dual purpose breed that belongs to Simmental population, one of the most numerous cattle population in the world. Its milking aptitude was improved in the past century by the cross with the Simmental Montbeliarde breed and the final aim of its genetic improvement is to optimize both milk and meat yield.

Muscularity (MU), which has been defined as the thickness of muscle relative to the dimensions of the skeleton (De Boer et al., 1974), has been included in selection indices of dual purpose cows such as the Italian Simmental (http://www.anapri.it) and beef breeds such as Piemontese (http://www.anaborapi.it), Chianina, Marchigiana and Romagnola cattle (http://www.anabic.it). The trait of MU can be scored in different moments of cows life: in living cows or in carcasses of slaughtered cows. In carcasses, in Europe, muscularity scoring is based on SEUROP method (European Commission, 1991, 1999, 2006). The Italian Simmental Cattle Breeders Association (ANAPRI) routinely records data for MU and BCS. These two traits were included in 1999 in the conformation evaluation system of the breed that includes now a total of 30

linear type traits scored by professional classifiers once in life for all registered first-parity cows. Evaluations are performed starting from 10-15 DIM on primiparous cows. Few studies have considered the genetic aspects of MU in dual purpose breeds: De Haas *et al.* (2007) found negative correlations of MU with production traits in Red and White breed, suggesting that animals with high genetic merit for partitioning energy into muscle growth have low genetic merit for producing milk. In Italian Simmental cattle the interest for functional parameters such as MU and BCS in genetic selection increased in recent years as a mean to improve and maintain the production efficiency of healthy cows. To describe the energy and muscle balance in a dual purpose breed, this paper aimed to investigate the genetic aspects of MU and BCS and to trace their expected patterns over DIM in the Italian Simmental breed. Specific objectives were: i) the estimation of genetic parameters for BCS and MU; ii) the estimation of genetic correlations between BCS, MU and production traits; iii) the calculation of expected patterns for BCS and MU along the lactation.

Materials and methods

Data

Data for BCS, MU, and test-day yields of milk (MY), fat (FY), and protein (PY) were collected by ANAPRI on primiparous cows from January 1999 to March 2007. A total of 48,542 records were available. Values of MU ranged from 1 (highly concave thigh profiles) to 9 (highly convex thigh profiles) with increments of 1 unit. Values of BCS were based on a 5 point scale with increments of 0.25 unit (from very thin to obese). Simplified BCS and MU score charts are reported in Figures 1 and 2. Both BCS and MU were scored once in primiparous cows from 6 to 360 DIM. The data editing imposed that heifers had calved from 20 to 42 months of age. Only one test-day production record was used in the analysis choosing the closest one to the scoring day of BCS and MU. Records with more than 50 kg/d and less than 5 kg/d of milk production were dropped from the final dataset. Ranges of fat (between 1 and 5%) and protein content (from 1 to 4%) were also required. The final dataset included 47,839 records on BCS, MU and production traits of Italian Simmental heifers reared in 2,794 herds. Genealogic information was extracted from the Herd Book of the breed including all known ancestors for a total of 1,114,129 animals.

Genetic parameters estimates

Environmental factors included in the models of analysis were previously tested for their significance with the GLM procedure of SAS (2000). (Co)variance components were estimated using the VCE package (Groenveld *et al.*, 2010) based on a REML algorithm. The estimation of variance components was performed in seven 2-trait multivariate analyses that included BCS or MU with one of the following production traits: MY, FY, or PY; and BCS with MU. The following animal model was used for BCS and MU:

$$y_{ijmnrsk} = ym_i + DIM_j + h_m + age_n + prod_r + classf_s + a_k + e_{ijmnrsk}$$

where
$y_{ijmnrsk}$ = BCS or MU;
ym_i = effect of year-month of calving (148 levels);
DIM_j = effect of days in milk (36 ten days classes from day 6 to day 360);
h_m = effect of herd (2,794 herds);
age_n = effect of age at calving classified in 3 classes (class 1: ≤25 months, class 2: from 26 to 32 months, class 3: ≥33 months);
$prod_r$ = effect of milk yield classified in 5 classes (class 1: ≤18 kg/d, class 2: from 18 to 22 kg/d, class 3: from 22 to 26 kg/d, class 4: from 26 to 40 kg/d, class 5: >40 kg/d);
$classf_s$ = classifier-year of data collection (189 levels);
a_k = additive genetic effect of animal k;
$e_{ijmnrsk}$ = random residual error.

Production traits of MY, FY and PY were analyzed with an animal model similar of the one used for BCS and MU except for the effects prod and classf that were not included in the analysis. All the effects included in the models were considered fixed except for the additive genetic effect of animal that was considered as random. The complete pedigree was considered in all models.
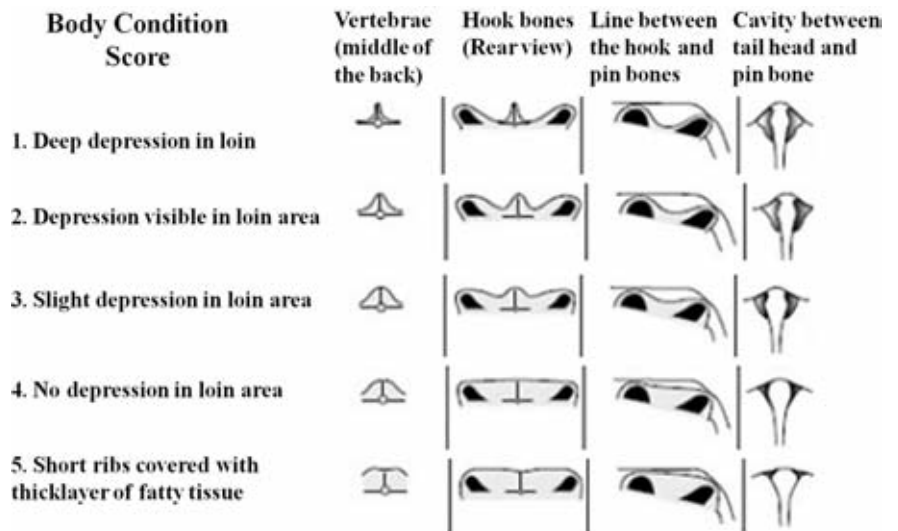

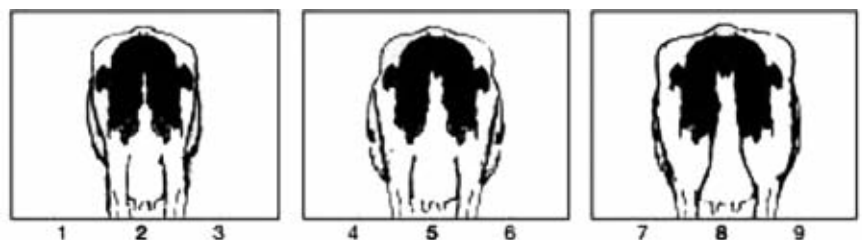Figure 1. Simplified body condition score chart (adapted from Krukowsky, 2009).

Figure 2. Simplified muscularity score chart (Source: www.anapri.it).

Body condition score and muscularity trend functions estimates

Fixed effects solutions for DIM classes obtained from univariate analyses for BCS and MU using the model described before, were used to estimate the expected patterns of these traits along the lactation. Several different functions were fitted using SAS procedures of REG, RSQUARE and STEPWISE (SAS, 2000) for both traits. In order to find the regression function that best fitted the data, the exponent of DIM varied from 1 to 3.9, with increments of 0.1, and all possibilities were considered in the multivariate model. Two expected patterns, one for each trait, BCS or MU, were chosen in order to obtain two trends with a biological meaning and a high statistical significance. Criteria of choice were the biological trend expected for these traits and the level of R-square resulting from each of the many functions considered.

Results and discussion

Descriptive statistics

Means and standard deviation of BCS, MU and milk production traits are given in Table 1. Mean (SD) of BCS was 3.49 (0.30), a value indicating a fair amount of subcutaneous adipose tissue during lactation. The distribution of BCS is plotted in Figure 3, which shows that the most frequent values of BCS were between 3.25 and 3.50, followed by values between 3.00 and 3.25. The skewness and kurtosis values for BCS were 0.11 and 1.21, respectively. Scores less than 3 or greater than 4 were rare. The BCS values were generally higher than what usually reported in dairy cattle (Pryce *et al.*, 2001; Kardarmideen, 2004), and decreased from the beginning of lactation by 0.05 points, with a gaining start soon after the nadir at about 60 DIM (Figure 4). This may indicate

that the deepness of the energy deficiency and its duration was moderate; this may be attributed to the nature of the breed, a dual purpose population, or to the data set including only first parity cows. According to dairy cattle literature, primiparous cows do not present a decrease in BCS so high as in multiparous cows both in Holstein (Roche *et al.*, 2007, Mäntysaari and Mäntysaari, 2010) and in Jersey cows (Rastani *et al.*, 2001). In Jersey cows the decrease in fat deposit (*i.e.*, the BCS reduction) was smaller than in Holstein cows (Rastani *et al.*, 2001) probably due to the mobilization of internal fat depots in early lactation.

The distribution of MU is plotted in Figure 5. The skewness and kurtosis values for MU were -0.52 and 0.27, respectively. The score of MU decreased by 0.15 points from the beginning of lactation to the increase after 60 DIM (Figure 6). Hence MU scores followed the same trend described for BCS reaching the nadir point at the same lactating week. The slight decrease
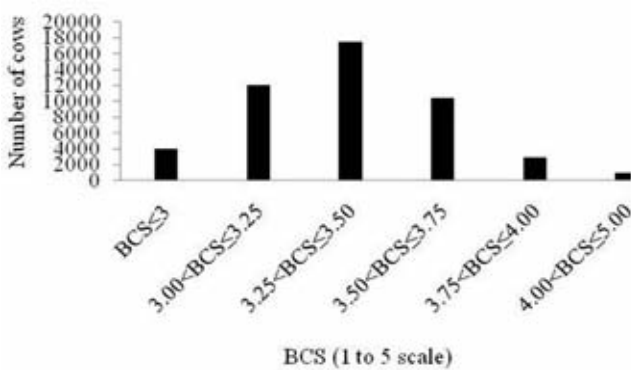

Figure 3. Distribution of body condition score (BCS) in the Italian Simmental cattle.
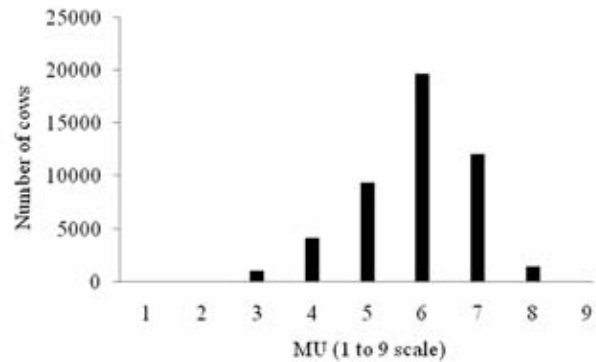

Figure 5. Distribution of muscularity (MU) in the Italian Simmental cattle.
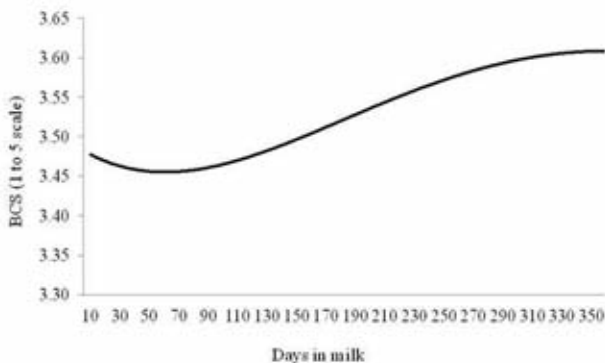

Figure 4. Trend of body condition score (BCS) during lactation in Italian Simmental cattle.
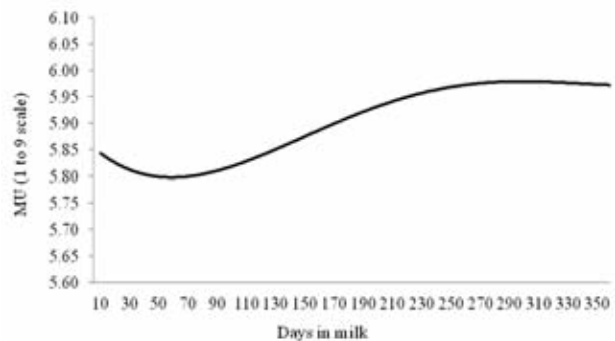

Figure 6. Trend of muscularity (MU) during lactation in the Italian Simmental cattle.

of MU in early lactation indicates that cows utilize, besides fat reserves, also muscle proteins to supply amino acids for gluconeogenesis and for milk protein synthesis as suggested in literature (Komaragiri *et al.*, 1997; Chibisa *et al.* 2008). Protein reserve use is of primary importance in breeds that include in their purposes the meat production, as *e.g.*, the Italian Simmental breed, justifying the inclusion of MU within linear type traits evaluated. Both MU and BCS decreased in early lactation in the Italian Simmental although BCS decreased in a lower amount if compared to high milk producing populations.

Tamminga *et al.* (1997) reported that in Dutch Friesian and Holstein Friesian cows the mobilization of body reserves, and the relative composition of tissues involved, were different over the lactation. Protein mobilization decreased faster than fat mobilization: protein mobilization changed in protein accretion after about 4 weeks, whereas mobilization of fat continued. In the present study, protein and fat mobilization decreased jointly by reaching the nadir point in the same lactation days. This would confirm that in dual purpose cows in early lactation both fat and muscle reserves are commonly used, differently from dairy cattle breeds.

The performances of BCS and MU during lactation that was observed in the present study is in agreement with results obtained in Simmental cattle by Gredler *et al.* (2006), and De Haas *et al.* (2007). Average test-day MY, FY, and PY were 24.13 kg/d, 0.74 kg/d, 0.65 kg/d, respectively, and fat percentage and protein percentage were 3.93 and 3.43 respectively, with values comparable with previous estimates in a Simmental populations (De Haas *et al.*, 2007) and similar to the official values

reported for the breed in Italy (http://www.anapri.it).

Heritability of body condition score and muscularity, and genetic correlations with production traits

Estimates of heritability, genetic and phenotypic correlations between BCS, MU and production traits are presented in Table 2. The heritability and the genetic correlations are the averages of seven estimates obtained from the pertinent seven 2-trait multivariate analyses.

The estimated BCS heritability was 0.18. Dal Zotto *et al.* (2007) reported a similar value (0.15) in the Italian Brown Swiss population using a multiple trait animal model.

The heritability value estimated in the present study is in the range of values reported by Dechow *et al.* (2001) for BCS recorded on second-parity Holstein cows, estimated with a multivariate animal model (0.07-0.20). Also, Bastin *et al.*, (2010) reported a similar value for BCS heritability (0.13) in Canadian Ayrshires and Holstein cows. Some authors reported higher values for BCS heritability both for dairy cows (Banos *et al.*, 2004; Pryce and Harris, 2006; Zink *et al.*, 2011) and dual purpose cows (Gredler *et al.*, 2006). Differences in BCS heritability estimates may be due to the scoring system (*e.g.*, Pryce and Harris (2006) used a visually 1 to 9 scale for BCS), the purpose of the breed (dairy cows or dual purpose cows), the data collection system (precision and consistency among classifiers), and finally the model of analysis (*i.e.,* random regression models) were used in Pryce and Harris (2006). Heritability of MU was 0.38. With multiple traits sire model, De Haas *et al.* (2007) estimated, for Red and White cows, val-

ues for MU heritability (0.59) higher than the one here reported, while similar values (0.22 to 0.35) were estimated for MU traits in beef cattle using linear mixed animal models (Crowley *et al.*, 2011). Heritabilities estimated for MY (0.18), FY (0.17), and PY (0.13) were slightly lower than those reported in other studies in dairy breeds (Pryce *et al.*, 2000; Kardamideen and Wegmann, 2003; Pryce et Harris, 2006), but similar to values estimated for the Italian Brown Swiss (Dal Zotto *et al.*, 2007). The genetic correlations between BCS and yield traits were negative (from -0.17 to -0.39) and comparable in magnitude and direction to estimates reported in dairy cattle (Berry *et al.*, 2002; Dechow *et al.*, 2002; De Haas *et al.*, 2007) indicating that also in dual purpose breeds lipid mobilization is necessary to sustain milk production. The genetic correlations between MU and yield traits were negative too (from -0.55 to -0.63) and were comparable in magnitude and direction to estimates reported in the study of De Haas (2007) in Red and White Swiss breed. According to the suggestion of Royal *et al.* (2002), these values implies that the gluconeogenesis involved in milk production leads to the mobilization of energy from tissues and both from fat or protein reserves. The genetic correlation between BCS and MU was highly positive (0.88) indicating that cows genetically inclined to have high BCS are more likely to have high values of MU and that selection for BCS would indirectly improve MU.

This high value of genetic correlation may suggest that the genetic selection could be based on one of the two traits neglecting the other one. The phenotypic correlation estimates of BCS, MU and yield traits were in the same direction as genetic estimates.

Table 1. Means and standard deviations of body condition score (scored from 1 to 5 points), muscularity (scored from 1 to 9 points), and yield traits in Italian Simmental cattle.

	Mean	SD
BCS	3.49	0.30
MU	5.87	1.07
Milk yield, kg/d	24.13	4.74
Fat yield, kg/d	0.74	0.20
Protein yield, kg/d	0.65	0.37

BCS, body condition score; MU, muscularity.

Table 2. Heritability (±SE) (diagonal), genetic (below) and phenotypic (above) correlation estimates of body condition score, muscularity, milk, protein, and fat yields in the Italian Simmental cattle°.

	BCS	MU	MY, kg/d	PY, kg/d	FY, kg/d
BCS	0.18±0.007	0.50	-0.15	-0.12	-0.11
MU	0.88±0.002	0.38±0.003	-0.15	-0.09	-0.13
MY, kg/d	-0.39±0.030	-0.55±0.005	0.18±0.006	0.88	0.65
PY, kg/d	-0.17±0.001	-0.53±0.002	0.81±0.003	0.13±0.004	0.70
FY, kg/d	-0.31±0.001	-0.63±0.002	0.46±0.002	0.68±0.004	0.17±0.003

°Heritabilities are average of all estimates obtained from 7 bi-trait models. BCS, body condition score; MU, muscularity; MY, milk yield; PY, protein yield; FY, fat yields.
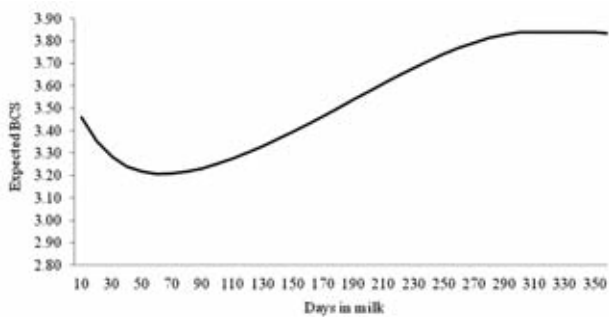
Figure 7. Expected pattern of body condition score (BCS) interpolating the mixed model solutions for days in milk in Italian Simmental cattle.
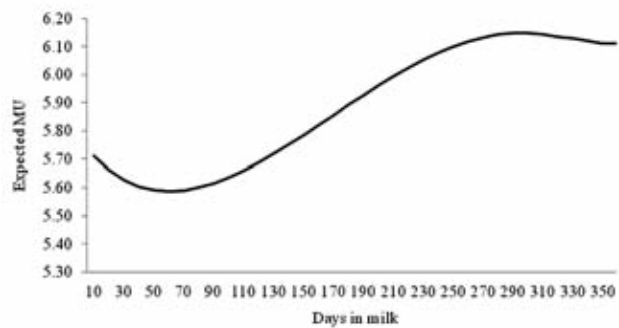

Figure 8. Expected pattern of muscularity (MU) interpolating the mixed model solutions for days in milk in the Italian Simmental cattle.

Estimation of expected patterns of body condition score and muscularity

The pattern function estimated for BCS along first lactation was:

$$y_i = 0.1532 - 0.253*(DIM) + 0.4957*(DIM)^2 - 0.507*(DIM)^{2,3} - 0.00005*(DIM)^{3,9}$$

where y_i is the estimated BCS for each class of DIM.

The pattern function estimated for MU along first lactation was:

$$y_i = -0.0948 - 0.0803*(DIM) + 0.0355*(DIM)^2 - 0.0229*(DIM2)^{2,1} - 0.00002*(DIM)^{3,9}$$

where y_i is the estimated MU for each class of DIM.

The expected patterns (Figures 7 and 8) provided the best fit to observed data ($R^2 = 0.81$). As presumed, the predicted pattern of BCS and MU reflected the biological pattern of each trait over DIM and the estimated nadir in both traits occurred nearly at the same DIM of the observed BCS and MU. Coefficients to predict and pre adjust BCS and MU for DIM may be calculated. Coefficients to pre-adjust BCS and MU values at a measure taken at the same stage of lactation, would permit the account of the stage of lactation independently from other fixed effects included in the model of EBV. Also, they would permit the prediction of expected BCS and MU in other stages of lactation different from the one in which BCS and MU are scored; by consequence the comparison of scores among cows evaluated in different lactation stages may be done. Using the expected patterns, coefficients for BCS and MU for each class of DIM may be calculated

with the following formula:

$$Coeff_i = \mu_m / \mu_i$$

where
μ_m is the average of BCS and MU at the nadir point;
μ_i is the average of BCS and MU at the i-class of DIM.

The management of BCS and MU has important implications for milk, herd health, reproductive performances, animal well-being and overall farm profitability. Adequate fat reserves promote milk production, reproductive efficiency and herd longevity (Bewley *et al.*, 2008). Excessively fat cows, or overly thin cows, have a great risk of metabolic problems, lower milk yield, poor conception rates and dystocia (Bewley *et al.*, 2008). A British research (Jones *et al.*, 1989) indicated that fat cows at calving (condition score 4 to 5) have a long delay between the peak of milk yield and the peak of food intake and cannot reach the maximum feed intake and prolong the period of negative energy balance. On the other hand, less conditioned cows at calving (condition score 3) have higher feed intake that more closely coincides with peak milk yield.

To support the amino acids need for the basic maintenance functions and to produce milk, cows mobilize protein reserves since the amino acids can provide about 12% of the lactose in milk. Protein may be easily equilibrated with the diet reducing therefore the period of protein deficiency and the failure in regaining body condition. So it is necessary to equilibrate the dietary protein during the early lactation. The expected patterns for BCS and MU would be helpful to evaluate the status of the animal and to formulate the best strategy for the herd. They would allow to predict the energy and protein balance during lactation and consequently

to formulate the best ration to meet the animals needs.

Conclusions

Similarly to all lactating cows, Italian Simmental cows mobilize fat and protein in early lactation though at lower intensity, to face the energy effort required by the production demand. The expected pattern of BCS values over DIM reflects the lipid mobilization. MU behavior reflected BCS changes, suggesting that proteins, as lipids, sustain the early lactation.

The high positive genetic relationship between muscular development and fat deposit amount could be favorable in a joint genetic selection of both traits. The expected patterns of both BCS and MU were predicted in the breed as an extra tool to take advantage in the management of both traits. Both traits, BCS and MU, present expected patterns that can be utilized by for feeding strategies.

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