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RELATIONSHIP BETWEEN MILK SOLIDS YIELD EFFICIENCY AND POSTPARTUM BODY WEIGHT IN A PASTORAL DAIRY FARM IN CHILE

ASOCIACIÓN ENTRE EFICIENCIA DE PRODUCCIÓN DE SÓLIDOS EN LECHE BOVINA Y PESO POSTPARTO EN UN SISTEMA PASTORAL EN CHILE

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ABSTRACT

In Chile, dairy industries pay for raw milk based on kg of milk solids (fat + protein). Productive efficiency can be defined as kg of milk solids per unit of land, and it is necessary to use biologically efficient cows to achieve high productive efficiency. Productive efficiency was defined as kg of milk solids output per kg of cow metabolic postpartum body weight. Genetic and phenotypic correlations between productive efficiency and postpartum body weight were estimated. Data were obtained from a research farm in Los Lagos region of southern Chile. A bivariate mixed linear model was used to estimate (co)variance components of the traits. Heritability estimates for productive efficiency and postpartum body weight were 0.35 ± 0.05 y 0.33 ± 0.05, respectively. Genetic and phenotypic correlations between the same traits were -0.65 ± 0.09 and -0.70 ± 0.12, respectively. It is concluded that there exists additive genetic variation for productive efficiency, which can be used in genetic selection programs, and there is an undesirable association between postpartum body weight and productive efficiency.

Key words: efficiency, genetic correlation, milk solids, body weight

RESUMEN

En Chile varias plantas receptoras de leche cruda pagan al productor lechero en base a kg de sólidos lácteos (grasa + proteína). La eficiencia productiva se puede expresar como kg de sólidos lácteos por unidad de superficie, y para alcanzar una buena eficiencia por unidad de superficie es necesario contar con vacas biológicamente eficientes. En este trabajo se estimaron correlaciones genéticas y fenotípicas entre eficiencia productiva y peso post parto. La eficiencia productiva fue definida como kg de sólidos lácteos por kg de peso metabólico postparto. Los datos provienen de un plantel experimental de la Región de Los Lagos en Chile. Se usó un modelo lineal mixto bivariado para la estimación de componentes de (co)varianza. Las estimaciones de heredabilidad para eficiencia productiva y peso postparto fueron 0,35 ± 0,05 y 0,33 ± 0,05, respectivamente. Las correlaciones genética y fenotípica, entre eficiencia productiva y peso postparto, fueron -0,65 ± 0,09 y -0,70 ± 0,12, respectivamente. Se concluye que existe variación genética aditiva para eficiencia productiva, la cual puede ser utilizada en programas de selección genética, y que hay una asociación negativa entre peso postparto y eficiencia productiva.

Palabras clave: eficiencia, correlaciones genéticas, sólidos en leche, peso corporal

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INTRODUCTION

Los Lagos and Los Ríos regions account for 72% of the dairy production in Chile, which is an important economic activity in the rural southern area of Chile (ODEPA 2018). Holstein Friesian, and its crosses, is the predominant dairy breed in southern Chile. Due to the fact that the Chilean dairy sector has not implemented its own genetic improvement program either at a national or regional level, there is no estimation of additive genetic values. In fact, most of the frozen semen purchased by Chilean dairy farmers is from the Holstein Friesian breed imported from the United States of America. This phenomenon, which started at the beginning of the 80s, was known in Chile as "*Holsteinization*" and resulted dueto the superiority of Holstein Friesian cows over the local breeds in milk production. Thus, "*Holsteinization*" decreased the number of local cows as they were progressively replaced by crossbred Holsteins (Mujica and Ehrenfeld, 1993). As the Holstein Friesian breed has progressively replaced locally adapted Chilean breeds, both average cow body weight and cow maintenance feed requirements have also increased (Ledinek et al., 20198).

Higher milk yielding cows need additional feed to fulfil their nutritional requirements, which is normally purchased outside the farm. This acquisition adds extra milk production costs that need to be afforded by the dairy farmer. As concentrate feed prices have risen but the price milk processing companies pay farmers for their milk has remained roughly the same, dairy farmers from southern Chile are shifting from intensive production systems based on heavy concentrate supplementation, to seasonal grazing pasture feeding, where the aim is to optimize yields of milk and milk solids per unit of farmland (González-Verdugo et al., 2004). Larger size and higher yielding cows are genetically selected in an environment where total mixed ration is the unique feeding source. Therefore, they might not be the most suitable and efficient cow biotype in a production setting where the core feeding source comes from direct grazing in a seasonal pastoral system (Macdonald et al., 2008).

In Chile, most dairy processing industries pay for fresh milk based on kg of milk solids (fat + protein), and litres or kg of milk do not get direct payment, hence, the economic success of the pastoral Chilean dairy farmer is currently dependant on milk solids output per unit of farmland (Delgadillo et al., 2016). Production efficiency can be understood as kg of milk solids per unit of land. However, to achieve production efficiency, it is necessary to feed biologically efficient cows. Ross et al. (2015) define biological efficiency as the production or energetic efficiency of dairy systems, in their study, they used four measures of production efficiency and two measures to asses energetic efficiency.

It is well known that larger, heavier cows yield a larger volume of milk compared to smaller cows, and consequently produce a greater output of milk solids. As body size differs among cows, even within a breed, it would not be totally correct to assess production efficiency solely as kg of milk solids per cow. The same would happen if milk solids yield per kg of body weight were used to evaluate production efficiency since this simple definition of production efficiency does not consider the amount of energy intake needed to produce a given amount of milk solids per kg of body weight. A more accurate method to assess efficiency is kg of milk solids yield per kg of metabolic weight, because energy expenditure depends on the amount of metabolically active tissue in the body and not on a cow's total body weight. An approximation to calculate active tissue is the metabolic weight, which is calculated as the total body weight to the power 0.75 (Da Silva et al., 2006). Metabolic weight is an approximation to the value of the cow tissue that uses maintenance energy.

Production efficiency, as defined above, could change as total body weight does, and high yielding cows might not be desirable when productive efficiency is measured as kg of milk solids per kg of metabolic postpartum body weight. The aim of this study is to quantify genetic and phenotypic associations between milk solids production efficiency and postpartum body weight.

MATERIALS AND METHODS

Traits

Production efficiency was assessed as kg of milk solids yielded in a lactation, per kg of metabolic postpartum weight; the second trait of this study was postpartum body weight (kg).

Data

Most studies of this type do not use data obtained from an experimental set up but from records collected over many years. In this study, postpartum body weight records were gathered from 1995 to 2015 at Oromo Dairy Research Farm of the Universidad de Chile, located in Purranque County (40º53′ South; 73º06′ West; 114 meters above sea level), Osorno Province, Los Lagos Region in southern Chile. At Oromo Research Farm, all cows are weighed within 12 hours after calving and milk yield records are collected on a monthly basis by an external and independent milking recording company, which provides whole lactation records estimated as the sum of monthly yields. Monthly yields are estimated as the corresponding test day yield multiplied by the number of days until next test day.

Dairy farmers in Chile do not systematically record body weight, and consequently data on this trait are not often available. Oromo dairy research farm runs a seasonal grazing dairy operation where the addition of concentrate and/or other external feed is minimal. Most calving occurs from June to August and concentrate feed (up to four kg cow^{-1} day^{-1}) is offered from June to September. Thus, late-calving cows (September) receive much less concentrate in the same lactation compared to a cow calving in early June. September marks the start of the grass growing season that reaches its peak at the beginning of November. In this system, the herd's calving season is synchronized to pasture growth to match up cows' nutritional needs. Milking stops towards the end of May (end of autumn) when all cows go dry. Artificial insemination is generally done using frozen semen of New Zealand bulls with above average estimated breeding values for milk solids yield according to their domestic genetic evaluations. Milk yield has not been a criterion for choosing bulls and attention has been paid to keep cows' body size constant.

The type of cow at Oromo Research Station has a lower milk yield and a smaller body size compared to modern Holstein Friesian cows from the North American strain. In Chile, this breed is known as Frisón Negro and it is similar to New Zealand Holstein. Frisón Negro is a local dairy breed that at present it is not very popular witin dairy farmers of Los Ríos and Los Lagos regions in southern Chile. The reduction in the population of Frisón Negro in Chile started in the eighties when the "holsteinization" process began. At that time, local dairy farmers preferred breeding their cows to US and Canadian Holstein Friesian bulls with the aim of getting higher milk output per cow (Mujica and Ehrenfeld, 1993).

The raw data set was edited, and inconsistencies and/or outliers were deleted. Outlier records were those farther than three standard deviations above or below from the mean. Lactation length was delimited from 100 and up to 330 days in milk. The final data set comprised 812 cows, which accounted for the 2,601 records that remained in the data set. Additionally, 214 ancestors from the pedigree files were included in the analysis.

The data set was analyzed using a bivariate animal model solved by best linear unbiased prediction (BLUP) (Henderson, 1984).

Statistical model

The theory of multivariate linear models can handle different models for the traits included in the analysis. Therefore, postpartum body weight was modelled as a function of the fixed effects of lactation number and contemporary group (cows calving in the same year and season), and the random effects of animal additive genetic and permanent environment. The same effects were included in the model of production efficiency, plus days in milk and milk yield as covariates. Cows calving from June to October were grouped in one calving season class, while cows calving from November to May of the following year were grouped in another class.

In matrix notation the bivariate model was:

$$\begin{pmatrix} y_1 \\ y_2 \end{pmatrix} = \begin{pmatrix} X_1 & 0 \\ 0 & X_2 \end{pmatrix} \begin{pmatrix} b_1 \\ b_2 \end{pmatrix} + \begin{pmatrix} Z_1 & 0 \\ 0 & Z_2 \end{pmatrix} \begin{pmatrix} a_1 \\ a_2 \end{pmatrix} +$$

$$\begin{pmatrix} P_1 & 0 \\ 0 & P_2 \end{pmatrix} \begin{pmatrix} p_1 \\ p_2 \end{pmatrix} + \begin{pmatrix} e_1 \\ e_2 \end{pmatrix}$$

where: y_i is a vector of observations for the ith trait, b_i is a vector of fixed effects and covariates for the ith trait, a_i is a vector of random additive genetic effects for the ith trait, p_i is a vector of random permanent environmental effects for the ith trait, a_i is a vector of random residual effects for the ith trait. X_i, Z_i and P_i are incidence matrices relating records of the ith trait to fixed, random additive and random permanent environmental effects, respectively.

The (co)variance structure of the bivariate model was:

$$Var\begin{pmatrix} a_i \\ p_i \\ e_i \end{pmatrix} = \begin{pmatrix} G & 0 & 0 \\ 0 & P & 0 \\ 0 & 0 & R \end{pmatrix}$$

where the elements of the diagonal matrices P and R are the permanent $(\sigma^2_{p_i})$ and residual $(\sigma^2_{e_i})$ variances for the ith trait, respectively. The off-diagonal elements of the P matrix correspond to the permanent environmental covariance $(\sigma_{p_{1,2}})$ between efficiency and postpartum body weight; the off-diagonal elements of the matrix R are the residual covariances $(\sigma_{e_{1,2}})$ between both traits. The matrix has the following structure:

$$G = \begin{pmatrix} A\sigma^2_{a_1} & A\sigma_{a_{1,2}} \\ A\sigma_{a_{1,2}} & A\sigma^2_{a_2} \end{pmatrix}$$

where A is the additive genetic relationship matrix with dimension equal to the number of animals contained in the analysis, $\sigma^2_{a_i}$ is the additive genetic variance of the i^{th} trait and $\sigma_{a_{1,2}}$ is the additive genetic covariance between efficiency and postpartum body weight. The zero matrices in the off-diagonal elements of $Var\begin{pmatrix} a_i \\ p_i \\ e_i \end{pmatrix}$ given above indicate independence among genetic, permanent environmental and residual effects.

The variance components were estimated by restricted maximum likelihood (Groeneveld, 1994) using the AIREML software (Misztal, 2002).

RESULTS

Phenotype

Postpartum bodyweight averaged 483.8 kg and varied from 265 to 695 kg, while milk solids yield varied from 134 to 645 kg. Average production efficiency was 2.61 kg, varying from 1.13 to 6.23 kg of milk solids per kg of postpartum metabolic weight (Table 1).

In this type of model, solutions of the fixed effects are not estimations of the fixed effects themselves. However, differences among the solutions are estimable functions of the differences among the fixed effects.

Production efficiency was significantly affected by lactation number. The most efficient cows were in their first and second lactation; as lactation number increased production efficiency declined. First and second lactation cows significantly yielded 0.41 and 0.47 kg more milk solids per kg of postpartum metabolic weight than fifth and above lactation cows, respectively (Table 2). There were no significant differences (P > 0.05) in efficiency between first and second lactation cows.

The number of records also decreased as lactation number increased (Table 2). For instance, records in fourth lactation (338) were less than one-half the number of records of first lactation cows (703).

Postpartum body weight was also significantly affected by lactation number. First lactation cows were 101.6 kg significantly lighter than fifth and above lactation cows. As lactation number increased, and thus age, postpartum body weight also increased. Significant differences between lactation numbers were observed in terms of postpartum body weight and production efficiency. For example, fourth lactation cows were 21.60 kg heavier (P < 0.05) compared to third lactation cows. Table 2 compares the differences among fifth and later lactations versus first, second, third and fourth lactations, for both postpartum body weight and production efficiency.

Regression coefficient of production efficiency on days in milk was 0.004 ± 0.0002. Therefore, as lactations get longer, production efficiency increases. Similarly, as milk yield increases, so does production efficiency. Thus, per each additional kg of milk yield, efficiency increases in 0.00057 ± 0.000075 kg of milk solids per kg of metabolic weight.

Table 1. Number of observations (n), means, standard deviations and minimum and maximum values of postpartum body weight, milk solids yield, metabolic weight and production efficiency for cows of an experimental dairy cattle herd of Los Lagos region in southern Chile.

	n	Mean	Standard deviation	Minimum	Maximum
Body weight*	2,601	483.78	74.78	265.00	695.00
Milk solids yield *	2,601	390.88	84.14	134.00	645.00
Metabolic weight *	2,601	102.92	11.96	65.68	135.36
Production efficiency**	2,601	3.80	0.74	1.13	6.23

* = kg, ** = kg of milk solids per kg of postpartum metabolic weight.

Table 2. Differences for postpartum body weight and production efficiency between cows in their fifth and above lactations (648) and cows in previous lactations.

Lactation number	n	Postpartum body weight differences (kg)	Valor t	Pr > |t|	Production efficiency differences *	Valor t	Pr > |t|
1	703	-101.55	46.82	< 0.01	0.41	6.83	< 0.01
2	507	-81.74	42.31	< 0.01	0.47	7.63	< 0.01
3	405	-39.46	22.41	< 0.01	0.28	4.57	< 0.01
4	338	-17.86	10.89	< 0.01	0.14	2.21	< 0.05

* = kg milk solids per kg of postpartum body weight

Genetic parameters

The equations to be solved in the mixed model were 3,763, and they took 21 iteration rounds to reach the convergence criterion, which was set at 1.0 x 10^{-7} in the software parameter file. Phenotypic variance was the sum of the additive genetic, permanent environmental and residual estimated variances, and heritability was the additive genetic variance divided by the phenotypic variance. Table 3 shows genetic, permanent environmental, residual and phenotypic estimated variances, and heritability for production efficiency and postpartum bodyweight. According to their standard errors, the estimated heritabilities for both traits were significantly different from zero.

Genetic and phenotypic correlation estimates, between production efficiency and postpartum body weight, were -0.65 ± 0.09 and -0.70 ± 0.12, respectively.

DISCUSSION

Phenotype

The data set used in this study is rather small. However, it is the only one available in southern Chile. Under pastoral conditions, body weight is a trait that is not routinely recorded in dairy production herds. The advantage of this data set is its integrity because all observations had both traits recorded, also pedigree information is permanently recorded in this research farm. Mixed model methodology is able to handle different models for each trait (Henderson, 1984). In this study, the model explaining the variability of post-partum body weight did not include days in milk and milk yield as covariates since as they were included in the model for production efficiency.

Postpartum body weight averaged 483.8 kg (Table 1). This result is very similar to that reported by Lembeye et al. (2014) for New Zealand crossbred cows (Friesian x Jersey), with an average body weight of 483 ± 4 kg. In the same study (Lembeye et al., 2014), pure New Zealand Friesian cows weighed 504 ± 6 kg. Black and white cows used in this research, locally called Frisón Negro breed, are comparable to New Zealand Friesian as the research farm imports frozen semen of this breed. New Zealand Friesian cows, under seasonal grazing, were lighter (404 kg) than the cows used in this study, this result can be explained as a consequence of the negative selection emphasis on body weight of New Zealand genetic selection indexes (Alawneh, 2011). According to Kidane et al. (2018), Norwegian Red cows were heavier than the cows used in this study. Their small sample of 48 cows averaged 566 ± 46.7 kg. However, the Norwegian cattle is a different breed than that used in this study. North American Holstein Friesian is a heavier dairy breed, which explains the findings of Vallimont et al. (2010) who reported that the average body weight of Holstein cows in 11 tie-stall Pennsylvanian farms was 678 kg, while Ramatsoma et al. (2015) reported an overall mean of 570 ± 0.8 kg for live weight in a data set comprising 9,843 Holstein records.

Average milk solids yield per lactation was 390.9 kg, which is higher than the value reported by Lembeye et al. (2016). These authors found that New Zealand cows of medium production level averaged 353 kg of milk solids per lactation. However, a study conducted by Montaldo et al. (2017) reported an average milk solids yield (standardized to a 305-day mature equivalent basis) of 409 kg from a sample of 7,650 lactations for Chilean Overo Colorado breed. Comparison between these results by Montaldo et al. (2017) and those obtained herein, is not straightforward because, on the one hand, milk solids yields included in this study are actual, not standardized, and on the other hand, the Overo Colorado breed has larger body size than the type of cow used in this study. First lactation Egyptian Holstein Friesian cows had an overall mean of 477.20 kg of milk solids from a sample of 1,180 records (Gouda et al., 2017) and, as expected, this is nearly 100 kg higher than that reported here, due to the fact that Holstein Friesian are higher milk

Table 3. Estimates of additive genetic (σ_a^2), permanent environmental (σ_{pe}^2), residual (σ_e^2) and phenotypic (σ_P^2) variances, and heritability (h^2) of production efficiency and postpartum body weight from data of an experimental dairy cattle herd of Los Lagos region in southern of Chile.

Trait	σ_a^2	σ_{pe}^2	σ_e^2	σ_P^2	$h^2 \pm se$
Production efficiency	0.055	0.032	0.070	0.158	0.35 ± 0.05
Postpartum body weight	948.11	479.00	1,414.32	2,841.38	0.33 ± 0.05

h^2 estimated as: $\sigma_a^2 / (\sigma_a^2 + \sigma_{pe}^2 + \sigma_e^2)$

yielding cows. Pipino et al. (2019), researching on lactation curves and milk quality, predicted 414 kg as accumulated production of milk solids in a cross of Swedish Red and White and Holstein breeds, using data from three commercial farms in Argentina.

Genetic parameters

The heritability estimate for postpartum body weight was 0.33 ± 0.05, and falls in the lower range of previous estimates for this trait. Part of the data used in this study was also used in a four-trait animal model by Uribe and González (2018), where the estimated heritability for postpartum body weight was 0.43 ± 0.047. Other estimates of body weight heritability for Chilean dairy cows were not found in the literature. All other estimated heritabilities found in the literature were higher than that reported here. For instance, the estimation of Vallimont et al. (2010) was 0.60 ± 0.08 in commercial tie-stall Holsteins; Ramatsoma et al. (2015) estimated 0.74 ± 0.19; Toshniwal et al. (2008) estimated 0.46 ± 0.06 and Berry et al. (2003) reported 0.48.

The heritability estimate for production efficiency, as defined in this work (kg of solids per kg of metabolic weight), was 0.35. The trait analyzed here did not consider feed consumption, and thus it is somewhat a basic measurement of production efficiency. Other genetic parameter estimations of production efficiency as defined in this study were not found in the literature reviewed. Nevertheless, the heritability estimated here suggests that there is opportunity for genetic selection toward improvement of production efficiency, which in turn should improve economic efficiency. VandeHaar et al. (2016) indicated that feed efficiency is a very complex trait, this makes it difficult to develop a single definition but one approach can be the fraction of feed energy used in products, which require measuring individual cow feed consumption. However, this type of data is not available in Chile. Residual feed intake is defined as the difference between predicted and actual feed intake and, regardless of the cow's production level, it can measure feed efficiency, heritability for this trait was estimated at 0.17 (VandeHaar et al. 2016). Nevertheless, Vallimont et al. (2011) had estimated the same parameter at 0.01 a few years earlier.

In this study, genetic and phenotypic correlations between postpartum body weight and production efficiency were negative, recording -0.65 ± 0.09 and -0.70 ± 0.12, respectively. This indicates that heavier cows are less efficient than lighter ones. In this sense, Vallimont et al. (2011) studied net energy for lactation efficiency defined as 305 days fat corrected milk divided by 305 days net energy intake. They found that the genetic correlation between this trait and body weight was high and negative (−0.64 ± 0.14), and concluded that selection for higher yield and lower body weight would increase feed efficiency.

In a study of Uribe and González (2018), post-partum body weight was genetic and phenotypically associated to yield traits; these associations were positive and low. These authors concluded that as milk and milk fat and protein yields improve, body weight increases due to genetic selection. According to the results of this research, selection for increments in milk yield increase body size, which could be detrimental for production efficiency. Ledinek et al. (2019) studied the influence of body weight on efficiency parameters of four dairy cattle breeds in Austria, and concluded that there is an optimum body weight range for efficiency, and that cows with medium weights within a population, were the most efficient. Therefore, an additional increment in dairy cows' body weights should be avoided.

Cows with larger body size have higher maintenance cost and their productive efficiency (measured as product output per kg of body weight) is lower compared to smaller cows (Ramatsoma et al., 2015). This fact is already acknowledged by the New Zealand dairy selection index, which allocates a negative weight to body weight. In addition,VandeHaar et al. (2016) strongly recommend that the US dairy industry discontinue selecting for larger dairy cows. Furthermore, pasture-based dairy producers in the United States use a total merit selection index in which body weight has a negative economic weight (Gay et al., 2014).

Cow production efficiency does not only concern farmers' economic return, but it is also a community issue and modern society's awareness of efficient and sustainable use of resources. There are many definitions of measurement of feed or energetic efficiency. Their strengths and weaknesses are currently being discussed and the debate remains open (Hurley et al. 2016).

Genetic selection of dairy cattle has mainly concentrated its effort in enhancing milk yield. Miglior et al. (2017) reported that average American Holstein cow's milk yield moved from 2,000 to 10,000 kg of milk per year in the last 100 years. This increment has had a cost in terms of health, fertility and body size. In the last decade, selection emphasis has shifted to traits concerning animal health and welfare, and lately, because of societal pressure, traits related to environmental sustainability are being explored. Production, biological or feed efficiency are directly related to sustainability because a more efficient cow would have a lesser impact on the environment (VadeHaar et al. 2016).

Feed efficiency is an issue that has both economic and environmental impact. However, this trait has not been already looked after by the dairy breeding industry, most likely due to difficulties in gathering appropriate data from commercial farms because there is not an easy way to measure individual cow feed/energy intake.

CONCLUSIONS

This study presents a rather simple way to measure production efficiency and its results suggest that: a) there is additive genetic variation for production efficiency (h^2 = 0,35 ± 0.05), which can be capitalized in selecting more efficient dairy cows, thus reducing environmental impact, and b) there are undesirable genetic (-0.65 ± 0.09) and phenotypic (-0.70 ± 0.12) correlations between body size and production efficiency.

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