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Technical note

Estimation of genetic parameters for milk flow rate and conductivity traits in a robotic milking system

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Abstract:

This work aimed to estimate the variance components and genetic correlations for milk yield (MiY), mean flow rate (MnF), maximum flow rate (MxF), and electrical conductivity (EC) of milk, in a robotic milking system. IT was analyzed a total of 137 lactations from 110 primiparous and multiparous Holstein cows, with 42,009 observations, from 2018 to 2020 in a dairy herd in the state of Querétaro. Genetic evaluation was performed using a mixed regression animal model. To estimate heritability (h^2), the restricted maximum likelihood algorithm was used to calculate the variance components, the BLUE estimator and the BLIP predictor, for each of the variables subject to the research. The estimated h^2 for MiY (0.62) was the highest of those calculated, and h^2 was also estimated for MnF (0.44), MxF (0.33), and EC (0.28); it is considered that one of the aspects that influenced the values was the variability of each daily observation. Genetic correlations for MiY were negative for MnF (-0.6117) and MxF (-0.7666); in contrast, for the trait of EC (-0.1669), the correlation was low. The estimated genetic correlations for MxF were positive for MnF (0.7422) and EC (0.5351); finally, a positive genetic correlation was estimated for MnF and EC (0.3546). The results presented allow to understand the relationships between flow rate, conductivity, and yield, and they indicate the importance of these characteristics for a genetic selection program.

Keywords: Heritability, Milk yield, Electrical conductivity, Milk flow rate.

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In order to improve the production indicators of dairy cattle and modify the desirable frequency of genes in a population, genetic evaluation and selection programs are employed. These programs, based on knowledge of genetic parameters, have frequently been used for the selection of traits such as milk yield and composition, udder conformation, and animal longevity. Thanks to technological advances in milking equipment, it is easier to measure yield, milk flow rate, and electrical conductivity, characteristics that can be included in a selection scheme[1,2].

In order to increase animal production, it is important to know the genetic and environmental factors, and to work on those that can be improved[3]. The morphology of the animals is usually the first direct indicator of milk production and of the ease of correct and fast milking. Nonetheless, it should be borne in mind that environmental factors must be considered in order to express genetic potential[4].

The milk flow rate trait can be considered of great importance because it is associated with milking efficiency and udder health. The higher the milk flow rate, the shorter the time spent using milking labor and machinery, which significantly influences the economy of the establishment[5,6]; however, a higher milk flow rate decreases the tension of the teat sphincter, which increases the risk of mastitis and is associated with a greater number of somatic cells (SCC). On the other hand, slow flow rate is associated with incomplete milk extraction, which causes increased intramammary tension. Although increasing the milking speed per cow reduces costs, when planning to make selection based on milk flow rate, it is advisable to keep the flow rate at a medium level[7,8]. The speed of milk ejection depends on the pressure accumulated within the mammary gland. Thus, a greater amount of milk stored in the udder increases the intramammary pressure, with the consequent increase in the speed of milk let down. The release of oxytocin into the bloodstream is essential to trigger the let-down and ejection of milk[9].

The milking routine, the machine, and the animal itself are factors directly related to milk flow rate. There is a great influence of the milking technique and the vacuum level of the machine; for example, a vacuum higher than specified results in an increase in milk flow rate but irritates the nipple lining. At the same time, flow rate measurement allows the identification of animals with longer milk ejection times, which are negatively associated with production per milking[10,11]. One of the main problems is how to measure flow rate; Tancin *et al*[12] concluded that the maximum flow rate is a biologically significant measure since as the maximum milk flow rate increases, total milking time and the duration of plateau phase decrease. In addition, flow rate measurement has been used to monitor the efficiency of the milking equipment and estimate the production per milking[13], as well as to establish the most appropriate flow rate that determines the end of milking and does not affect cow comfort[14].

Electrical conductivity (EC) is the ability of a solution to conduct electric current; it is related to the concentration and mobility of milk ions, 60 % depending on its dissolved salt content[15]. EC has been considered as a trait that indicates udder health, being used for the prediction of mastitis in goats and cows[15,16,17]; the information is easy to record in automated systems. Therefore, EC could be useful not only for cow management but also as a selection trait. It has been mentioned that the high correlation between SCC and EC values holds promise for improving mastitis resistance and functional capacity of dairy cows. In automated systems, EC records are available within a few seconds after milking, making EC information useful for early detection of mastitis.

EC may fluctuate; it may vary between quarters, between milking phases, and due to the presence of mastitis. The components of the milk can also play a role as any change in the ion concentration will be reflected in the EC[16]. Other studies[18] have reported that milk production and EC change significantly at least one day before the onset of clinical mastitis.

Robotic milking systems (RMSs) record milking parameters related to yield, EC, and quarter and total flow rate for each event[19,20].

Genetic improvement programs are the cornerstone of increasing the efficiency of livestock production units and are based on increasing the frequency of desirable genes in a population of dairy cows[21,22]. The effectiveness of an improvement program will depend on the genetic variability of the population and, therefore, on the heritability of the traits to be improved. Carrying out genetic evaluations allows the identification of those animals with the greatest genetic potential for the traits of productive interest. In genetic programs, the parameters of heritability, repeatability, and genetic correlations are estimated.

By means of heritability, the extent to which the phenotypic variance corresponds to the variance due to the genes is estimated. These components determine the response to selection, establish the strategy to be used in the improvement of traits of interest, and are essential for the successful construction of decisions in selection and genetic improvement programs[23].

Although electrical conductivity and flow rate are important for increasing milk yield and are closely related to a decrease in production costs, there is not enough information on their genetic components or the influence this information would have on milk production.

The work was carried out in a cowshed that has a DeLaval VMS™ robotic milking system, located in the Municipality of El Marqués, Querétaro. This system permanently records the individualized information of each cow each time it enters the milking module. At each milking event, the system records the amount of milk produced per quarter and the total yield (kg), milking time (min), milk flow rate (kg/min), and conductivity (mS/cm).

The cows were integrated into the trial at the beginning of their lactation period; individual information was collected throughout the period. Information from cows that did not complete lactation for reasons beyond the control of the project was discarded.

The management of the animals was based on one-way traffic; that is, the animals could be in the trough area, in the stall area, or in the milking module area, and circulate in that order, but they could not return to previous areas. The cows came to the milking module voluntarily and attracted by the offer of concentrated feed in the trough located in the module. Feeding consisted of the permanent offer of a partially mixed ration and a limited supply of concentrate in the milking module; the diet was formulated to meet the nutritional requirements of the animals. The cows were permanently monitored to carry out the necessary activities related to reproductive and health maintenance aspects; all in accordance with the practices established by the Veterinarian responsible for the establishment.

Information on milk yield in kg/day (MiY), electrical conductivity in mS/cm (EC), mean milk flow rate (MnF) in kg/min, and maximum milk flow rate in kg/min (MxF) was collected daily from 110 cows, of which 47 were in first lactation (FL), 45 in second lactation (SL), 28 in third lactation (TL), and 17 in fourth or more lactations (FoL), giving a total of 137 lactations. Table 1 shows the values recorded by calving year and Table 2 by calving season for the above-mentioned characteristics. The seasons were defined as follows: Season 1, the first 3 mo of the year; Season 2, mo 4 to 6; Season 3, mo 7 to 9; Season 4, mo 10 to 12. The yields reported by the cowshed are within the usual parameters for a high producing herd in Mexico.

Table 1: Average, minimum, and maximum values of the traits of milk yield (MiY), electrical conductivity (EC), mean milk flow rate (MnF), and maximum milk flow rate (MxF) per calving year

Variable	N	Minimum	Maximum	Mean	Std Error
			Calving year 2018		
MiY, kg/day	9313	0.41	114.54	38.61	0.140
EC, mS/cm	9313	1.97	6.65	4.57	0.004
MnF, kg/min	9313	0.25	2.70	1.21	0.004
MxF, kg/min	9313	0.52	3.62	1.68	0.005
			Calving year 2019		
MiY, kg/day	21205	0.95	134.70	39.86	0.087
EC, mS/cm	21205	0.99	7.84	4.59	0.003
MnF, kg/min	21205	0.24	5.15	1.23	0.002
MxF, kg/min	21205	0.37	13.49	1.72	0.003
			Calving year 2020		
MiY, kg/day	4965	5.83	85.18	41.92	0.180
EC, mS/cm	4965	1.57	6.85	4.77	0.008
MnF, kg/min	4965	0.35	2.21	1.18	0.004
MxF, kg/min	4965	0.54	3.00	1.66	0.005

Table 2: Average, minimum, and maximum values of the traits of milk yield (MiY), electrical conductivity (EC), mean milk flow rate (MnF), and maximum milk flow rate (MxF) by calving season

Variable	N	Minimum	Maximum	Mean	Std Error
			Calving season 1		
MiY, kg/day	8576	2.66	91.21	39.97	0.130
EC, mS/cm	8576	1.57	6.85	4.64	0.005
MnF, kg/min	8576	0.30	2.24	1.13	0.003
MxF, kg/min	8576	0.55	3.00	1.59	0.003
			Calving season 2		
MiY, kg/day	5408	6.44	84.85	39.20	0.153
EC, mS/cm	5408	0.99	6.38	4.54	0.006
MnF, kg/min	5408	0.24	2.19	1.24	0.004
MxF, kg/min	5408	0.37	2.96	1.72	0.004
			Calving season 3		
MiY, kg/day	6697	4.76	88.01	40.67	0.137
EC, mS/cm	6697	1.75	7.84	4.58	0.006
MnF, kg/min	6697	0.30	2.35	1.29	0.004
MxF, kg/min	6697	0.52	3.14	1.72	0.004
			Calving season 4		
MiY, kg/day	14802	0.41	134.70	39.58	0.120
EC, mS/cm	14802	1.34	7.50	4.64	0.004
MnF, kg/min	14802	0.25	5.14	1.24	0.003
MxF, kg/min	14802	0.52	13.49	1.75	0.004

The information was recorded daily, obtaining 1 to 4 records per day. For MiY, the total yield of each milking was summed per day, while for EC, MnF, and MxF, the values were averaged per day (total and per quarter). To make the lactation curve, the daily MiY was added, and then per week. To calculate the genetic parameters, a total of 137 observations were obtained for MiY, EC, MnF, and MxF (Table 3).

Table 3: Average, minimum, and maximum overall values of the traits of milk yield (MiY), electrical conductivity (EC), mean milk flow rate (MnF), and maximum milk flow rate (MxF).

	MiY, kg/day	EC, mS/cm	MnF kg/min	MxF kg/min
Average	39.82	4.61	1.22	1.70
Minimum	0.41	0.99	0.23	0.37
Maximum	134.7	7.84	5.14	13.49
Std Error	0.069	0.002	0.001	0.002

In order to identify the genetic effects, it was necessary to consider and correct for the environmental effects that could have an effect on the variables studied. Therefore, environmental effects were represented in the model, including the year and season of calving and the age of the animal at calving; in addition, the possibility of having permanent environmental effects (common to the same animal, but not genetic) was also considered as there was more than one record per animal.

The variance components for MiY, MnF, MxF, and EC were estimated per lactation with a repeatability animal model, eliminating atypical and extreme data. A mixed linear model was used, which included as fixed effects: the number of calvings/year/calving season (four seasons depending on the month of calving: January-March, April-June, July-September, and October-December). The animal and the permanent environment were included as random effects.

The estimators of the variance and covariance components were performed by means of restricted maximum likelihood and the heritabilities, repeatability, and genetic correlations were calculated from the variance components, using the BLUPF90 suite programs[24].

To estimate variance components, the model used was:

$$y_{ijklmn} = \mu + year_i + season_j + numc_k + animal_l + perenv_m + e_{n(ijklm)}$$

Where:

$\mathbf{y_{ijklmn}}$= vector of observations of interest (MiY, EC, MnF, and MxF) corresponding to observation n in calving year i, calving season j, calving number k, animal l, permanent environment m;

$\mathbf{year_i}$= effect of the calving year i;

$\mathbf{season_j}$= effect of calving season j (from 1 to 4);

$\mathbf{numc_k}$= effect of calving number k (from 1 to 4);

$\mathbf{animal_l}$= genetic random effect of the animal l,

$\mathbf{perenv_m}$= random effect of the permanent environment m;

$\boldsymbol{e}_{\mathbf{n(ijklm)}}$= vector of the error or residual effects of observation n within animal l, calving year i, calving season j, and calving number k.

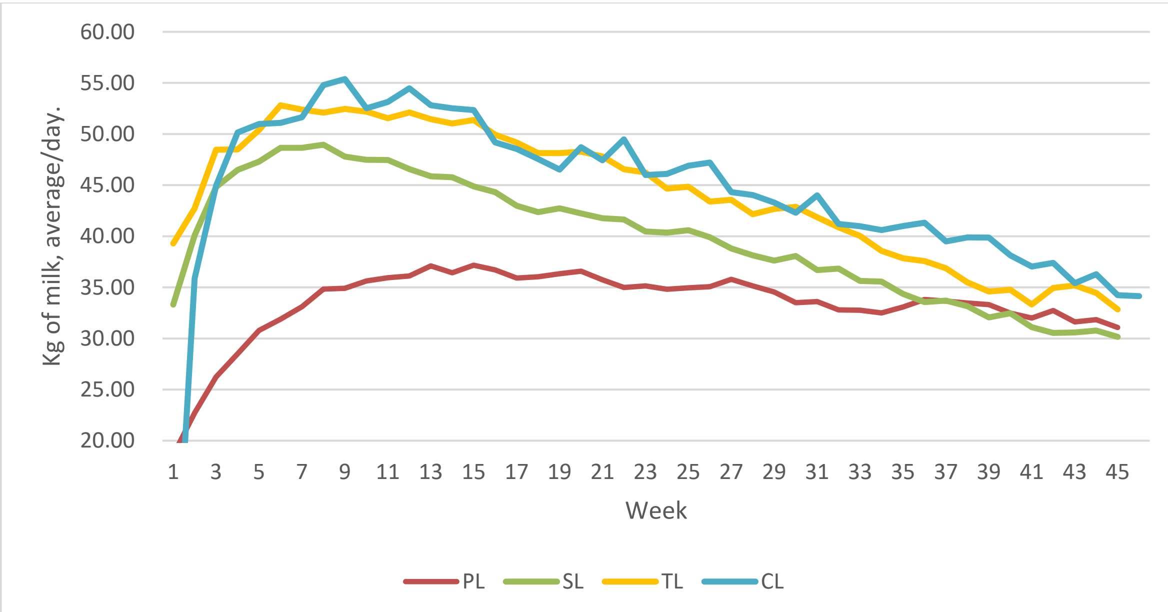
To estimate the components of covariance, bivariate analyses were performed using the following matrix model:

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} X_1 & 0 \\ 0 & X_2 \end{bmatrix} \begin{bmatrix} b_1 \\ b_2 \end{bmatrix} + \begin{bmatrix} Z_1 & 0 \\ 0 & Z_2 \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \end{bmatrix} + \begin{bmatrix} e_1 \\ e_2 \end{bmatrix}$$

Where subscripts 1 and 2 identify the pair of traits to be evaluated, $\boldsymbol{y}$ (MiY, EC, MnF, and MxF), b= fixed-effect vector (calving/year/calving season), u= random-effects vector (animal and permanent environment), X and Z are incidence matrices for vectors b and u, respectively; e= vector of error or residual effects.

Figure 1 shows the milk yield of cows by lactation number. First calving cows had lower yield and yield peak and greater persistence than cows with more lactations.

Figure 1: Daily milk yield over 45 weeks in cows in first lactation (FL), second lactation (SL), third lactation (TL), and fourth or more lactations (FoL)



The variance components calculated for milk yield, electrical conductivity, mean flow rate, and maximum flow rate, as well as heritability and repeatability are shown in Table 4.

Table 4: Variance components for milk yield (MiY), electrical conductivity (EC), mean milk flow rate (MnF), and maximum milk flow rate (MxF)

	MiY	EC	MnF	MxF
σ^2_A	183.60	0.110	0.055	0.065
σ^2_{PE}	23.74	0.099	0.082	0.109
σ^2_e	87.78	0.129	0.025	0.052
h^2	0.62	0.44	0.33	0.28
r^2	0.70	0.48	0.84	0.77

σ^2_A= additive genetic variance; σ^2_{PE}= variance of the permanent environment; σ^2_e= residual variance; h^2= heritability; r^2= repeatability.

The heritability of milk yield (0.62) was higher than the estimated values in Holstein cattle in Mexico; it has been reported between 0.17 and 0.49 for the first lactation and between 0.16 and 0.41 for the first five lactations[23]. A medium-high heritability value (0.44) was estimated for EC, similar to that estimated by other authors[25,26]; under automated milking conditions, as in this study, heritability was reported to fluctuate between 0.38 and 0.49[27]. It has been argued that the heritability of EC is important because the genetic correlations between EC and mastitis have been estimated to range from 0.65 to 0.8; therefore, obtaining the genetic response for mastitis should be possible by using EC information in genetic evaluation(17).

The estimated heritabilities for MnF and MxF were medium (0.33 and 0.28); in cows managed in automated milking systems, values of 0.47 to 0.58 were reported for MnF(27); similarly, in Italian Holstein-Friesian cows(28) under traditional milking, high heritability (0.50) was obtained for the initial milk flow rate and high heritability (0.54) for MxF.

Table 5 presents the genetic correlations for the traits studied. A negative correlation was estimated for MiY and EC (-0.167); other authors(29) also reported a negative correlation (-0.12), which suggests that selection made to increase milk production decreases EC.

Negative correlations (-0.612) were estimated for MiY and MnF, as well as for MiY and MxF (-0.767); in contrast, other authors(30), who worked with Jersey cows in tropical climates, estimated positive genetic correlations for these traits (0.46 to 0.89). The above should be reviewed since if the genetic correlations were negative as reported here, the increase in milking time would not be proportional to the increase in yield as the flow rate of milk would decrease, with significant decreases in milking efficiency.

Table 5: Genetic correlations between milk yield (MiY), electrical conductivity (EC), mean milk flow rate (MnF), and maximum milk flow rate (MxF)

	MiY	**EC**	**MnF**	**MxF**
MiY	1	-0.167	-0.612	-0.767
EC		1	0.3546	0.5351
MnF			1	0.7422
MxF				1

The relationships of EC with MnF and MxF were 0.35 and 0.53, respectively, values that contrast to those reported by some authors who worked with dairy goats and showed a negative relationship for MxF and EC (-0.003)(31).

The positive correlations found between the flow rate and conductivity traits allow to infer that the selection programs may be based on one of the three traits and show progress. Nevertheless, the negative correlations between milk yield and these characteristics, especially with flow rate traits, are contrary to what has been reported by other authors(30) and present a challenge for producers since milk yield is the most economically important characteristic in the production system and its improvement implies deterioration in the other traits.

The correlations between milk flow rate traits were high and positive (0.74), so it is not necessary to select for both variables when increasing milk flow rate is desired.

The present results allow a better understanding of the relationships between flow rates (average and maximum), conductivity, and milk yield, and indicate that the selection made to increase milk production has decreased EC, which implies that the average levels of EC will have to be recalculated periodically in order to interpret this parameter correctly. However, this improvement in MiY is associated with decreases in milk flow rates, so there is the potential to improve the efficiency of milk production by shortening the duration of milkings through increased flow rate, with consequent savings in milking costs. Negative genetic correlation will make the individual selection of these traits difficult, and their improvement will require the development of selection indicators that allow both traits to be improved at the same time.

Acknowledgments and conflict of interest

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The authors state that there is no conflict of interest.

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