Animal (2019), **13:1**, pp 83–89 © The Animal Consortium 2018
doi:10.1017/S1751731118000666

Development of equations, based on milk intake, to predict starter feed intake of preweaned dairy calves

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(Received 18 August 2017; Accepted 1 March 2018; First published online 16 April 2018)

There is a lack of studies that provide models or equations capable of predicting starter feed intake (SFI) for milk-fed dairy calves. Therefore, a multi-study analysis was conducted to identify variables that influence SFI, and to develop equations to predict SFI in milk-fed dairy calves up to 64 days of age. The database was composed of individual data of 176 calves from eight experiments, totaling 6426 daily observations of intake. The information collected from the studies were: birth BW (kg), SFI (kg/day), fluid milk or milk replacer intake (MI; l/day), sex (male or female), breed (Holstein or Holstein × Gyr crossbred) and age (days). Correlations between SFI and the quantitative variables MI, birth BW, metabolic birth BW, fat intake, CP intake, metabolizable energy intake, and age were calculated. Subsequently, data were graphed, and based on a visual appraisal of the pattern of the data, an exponential function was chosen. Data were evaluated using a meta-analysis approach to estimate fixed and random effects of the experiments using nonlinear mixed coefficient statistical models. A negative correlation between SFI and MI was observed ($r = -0.39$), but age was positively correlated with SFI ($r = 0.66$). No effect of liquid feed source (milk or milk replacer) was observed in developing the equation. Two equations, significantly different for all parameters, were fit to predict SFI for calves that consume less than 5 ($SFI_{<5}$) or more than 5 ($SFI_{>5}$) l/day of milk or milk replacer: $SFI_{<5} = 0.1839_{\pm 0.0581} \times MI \times exp^{((0.0333_{\pm 0.0021} - 0.0040_{\pm 0.0011} \times MI) \times (A - (0.8302_{\pm 0.5092} + 6.0332_{\pm 0.3583} \times MI)))} - (0.12 \times MI)$; $SFI_{>5} = 0.1225_{\pm 0.0005} \times MI \times exp^{((0.0217_{\pm 0.0006} - 0.0015_{\pm 0.0001} \times MI) \times (A - (3.5382_{\pm 1.3140} + 1.9508_{\pm 0.1710} \times MI)))} - (0.12 \times MI)$ *where MI is the milk or milk replacer intake (l/day) and A the age (days). Cross-validation and bootstrap analyses demonstrated that these equations had high accuracy and moderate precision. In conclusion, the use of milk or milk replacer as liquid feed did not affect SFI, or development of SFI over time, which increased exponentially with calf age. Because SFI of calves receiving more than 5 l/day of milk/milk replacer had a different pattern over time than those receiving <5 l/day, separate prediction equations are recommended.*

Keywords: age, growth, milk, milk replacer, modeling

Implications

This study demonstrated that milk intake and animals' age have great influence on starter feed intake (SFI). The findings of this work are interesting to the scientific community because it demonstrated that calf solid feed intake is driven by milk intake and age, and has an exponential pattern. In addition, our findings increase general knowledge about SFI of calves and may be used as a feasible tool for practical use to formulate diets.

Introduction

Feed intake is the most critical variable influencing animal performance because it determines the amount of nutrients ingested and their availability for maintenance and production (Nutrients Requirements Council, 2001). Thus, an accurate prediction of feed intake is necessary to develop balanced diets, avoiding under- or over-feeding, and to improve nutrients use and animal performance (Roseler *et al.*, 1997; NRC, 2001).

Mathematical models (Tedeschi and Fox, 2009 and 2018; Tedeschi *et al.*, 2013) and empirical equations (NRC, 2001; Hoffman *et al.*, 2008) have been developed to predict dry matter intake for animals of all categories, such as lactating cows and growing heifers. Further, a series of management and environmental conditions influencing those intake models have also been evaluated (Hayirli *et al.*, 2003; Krizsan *et al.*, 2014; Souza *et al.*, 2014). However, no models or equations have been developed to estimate dry matter intake, or more appropriately, SFI of preweaned dairy calves. This is due to a considerable variability presented by SFI, which causes obstacles for developing models or equations.

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Solid feed intake is important for promoting ruminal development and adaptation to future solid diets, and it is also used as a criterion for weaning in dairy calves (Silper *et al.*, 2014). It also influences body composition and, consequently, nutrient requirements (Silva *et al.*, 2015 and 2017). Thus, an accurate prediction of SFI is important for farm management, to determine weaning age, and to determine the composition of the starter feed that allows for meeting calf's energy and nutrient requirements.

The SFI may be influenced by several factors, such as form, quality and composition of starter feed, level of liquid feed intake, type of liquid feed (milk or milk replacer), composition of liquid feed (mainly protein and fat content), rate of growth, availability and cleanliness of water and animal age (Kuehn *et al.*, 1994; Khan *et al.*, 2011; Stamey *et al.*, 2012; Kertz and Loften, 2013). Among these variables, the level of liquid feed intake and animal age seem to have the most significant influence on SFI. Liquid feed intake is negatively associated with SFI, and decreases in SFI have been observed when liquid feed intake is increased (Jasper and Weary, 2002; Khan *et al.*, 2007; Sweeney *et al.*, 2010). Conversely, SFI is positively associated with age, which demonstrates that capacity of intake is linked to growth and gastrointestinal tract development (Kertz *et al.*, 1979; Silva *et al.*, 2015).

Therefore, we hypothesized that SFI is primarily influenced by liquid feed intake and it presents a different pattern for milk or milk replacer. In addition, we hypothesized that SFI demonstrates an increasing trend over time, according to animal age. Therefore, the objective of this study was to identify variables that influence SFI, and to develop predictive equations for SFI of preweaned dairy calves up to 64 days of age.

Material and methods

Our study compiled data from studies previously carried out. Thus, no animal care and use protocol was needed; however, all individual studies followed local guidelines for animal care and use. This study is part of the PhD thesis of Silva (2017).

Development of database

Data used were obtained from individual preweaned dairy calves ($n = 176$) from eight experiments, totaling 6426 daily observations of intake. Among these experiments, five studies were carried out at the Universidade Federal de Viçosa (Viçosa, Minas Gerais, Brazil) and three at the University of Guelph (Kemptville, Ontario, Canada) (Table 1). Information that was collected from the studies included: birth BW (kg), SFI (kg/day), milk or milk replacer intake (MI; l/day), sex (male or female), breed (Holstein or Holstein × Gyr crossbred) and age (days) (Tables 1 and 2).

Information about the feedstuffs used in each experiment is available in Supplementary Material Table S1. Because milk replacer contained more DM than raw milk, the consumed milk replacer amount was corrected to the average DM content of milk, being 120 g/kg.

Among the studies in this analysis, Miller-Cushon *et al.* (2013a and 2013b) and Overvest *et al.* (2016) used a textured starter feed. Conversely, Jolomba (2015), Silva *et al.* (2015),

Table 1 *Summary of the database used to develop and evaluate models to predict starter feed intake of preweaned dairy calves*

Author/year	*n*	PE	Liquid feed type	Sex	Breed
Silva *et al.* (2015)	18	15 to 64	Milk	Male	Crossbred
Rodrigues *et al.* (2016)	23	4 to 55	Milk	Male	Holstein
Marcondes *et al.* (2016)	20	6 to 60	Milk	Female	Holstein
Dias *et al.* (2017)	17	4 to 60	Milk	Male	Holstein
Jolomba (2015)	32	5 to 53	Milk replacer	Male	Crossbred
Miller-Cushon *et al.* (2013a)	20	8 to 42	Milk replacer	Male	Holstein
Miller-Cushon *et al.* (2013b)	10	8 to 56	Milk replacer	Male	Holstein
Overvest *et al.* (2016)	36	15 to 38	Milk replacer	Male	Holstein

n = Number of calves; PE = period, in days of life, under evaluation (not all calves had the intake evaluated during all period).

Table 2 *Descriptive statistics of the data used to develop and evaluate models to predict starter feed intake of preweaned dairy calves*

Variables	BW_b (kg)	Age (days)	SFI (kg/day)	MI (l/day)	FI (g/day)	CPI (g/day)	MEI (Mcal/day)
Minimum	22.5	1	0.00	2.00	49	61	1.21
Maximum	51.5	64	1.778	14.25	325	576	10.52
Mean	36.3	30.5	0.236	7.07	170	232	4.26
Median	35.0	30	0.128	6.00	152	215	4.03
Mode	35.0	23	0.020	6.00	120	151	3.09
SEM	0.075	0.188	0.003	0.052	0.7	1.1	0.020

BW_b = birth BW; SFI = starter feed intake; MI = milk or milk replacer intake; FI = fat intake; CPI = CP intake; MEI = metabolizable energy intake.

Marcondes *et al.* (2016), Rodrigues *et al.* (2016) and Dias *et al.* (2017) used ground (as meal form) starter feed. Forage was not provided to calves, during the liquid feeding phase, in the studies of Miller-Cushon *et al.* (2013a), Jolomba (2015), Silva *et al.* (2015), Marcondes *et al.* (2016), Rodrigues *et al.* (2016) and Dias *et al.* (2017). On the other hand, the studies of Miller-Cushon *et al.* (2013b) and Overvest *et al.* (2016) had treatments which included forage. However, because of the low number of animals that had access to forage, it was not possible to include this effect in our analysis; therefore, we removed these animals from our database.

Statistical analysis

Pearson's coefficients of correlation were determined between SFI and relevant quantitative variables (e.g. MI, birth BW, metabolic birth BW ($BW_b^{0.75}$, fat intake, CP intake, metabolizable energy intake and age). Subsequently, a preliminary graphical appraisal was carried out to identify the pattern of the data. As a result, an exponential function was chosen, as exposed by the general model below, which is in agreement with previous studies (Kertz *et al.*, 1979; Stamey *et al.*, 2012).

$$Y = \beta_0 \times \exp^{(\beta_1 (A - \beta_2))}$$

where Y = SFI (kg/day); β_0 = intercept; β_1 = intake increment rate (per day); A = age (days) and β_2 = adjustment parameter.

Because the data set was comprised observations from different studies, it was necessary to quantify this variance associated with the studies. Therefore, each experiment was considered as a random sample of a large population (St-Pierre, 2001) and the inclusion of experimental effects in the exponential model required the estimation of fixed effects, as well as random effects associated with the experiments, as described by Vyas and Erdman (2009).

Given the high influence of MI on SFI (Hill *et al.*, 2013; Miller-Cushon *et al.*, 2013a), each parameter of the general equation was replaced by a linear regression as a function of MI. In addition, an adjustment factor was added to convert DMI in SFI, generating the following exponential function:

$$\begin{aligned} Y_{ij} = {} & (\beta_0 + \beta_1 \times \mathrm{MI}) \times \exp^{((\beta_2 + \beta_3 \times \mathrm{MI}) \times (A - (\beta_4 + \beta_5 \times \mathrm{MI})))} \\ & - (0.12 \times \mathrm{MI}) + u_j + e_{ij} \end{aligned}$$

where Y_{ij} = SFI (kg/day) for the i individual observations (ranging from 1 to 6426) and j experiments (ranging from 1 to 8); MI the milk or milk replacer intake (l/day); A the age (days); $0.12 \times \mathrm{MI}$ the adjustment factor to convert DMI in SFI (based in the milk DM content, which averaged 120 g/kg); u_j the random effect of study; e_{ij} the random error associated with each observation, and β_1, β_2, β_3, β_4 and β_5 are equations' parameters.

The PROC NLMIXED of SAS (SAS Institute Inc., 2008) was used to fit the parameters of the equation (Supplementary Material S1). The effects of the type of liquid feed (milk or milk replacer) as well as MI were tested using the 'ESTIMATE' statement in PROC NLMIXED, and parameter coefficients were considered different when $P < 0.05$. The effects of sex, forage intake and breed were not tested because of the low number of female and crossbred calves. Observations with studentized residuals greater than $|2.5|$ were considered 'outliers' (Pell, 2000; Tedeschi, 2006) and excluded from the database.

Sensitivity analysis

First, the goodness of fit of the equations was evaluated using the dispersion of standardized residual of SFI (Souza, 1998). The standardized residual was obtained by the following relation:

$$\mathrm{SR}_i = \frac{y_i - \hat{y}_i}{\mathrm{ASD}}$$

where SR_i is the standardized residual; y_i the observed value; $\hat{y}_i$ the estimated value and ASD the asymptotic standard deviation.

The values of the asymptotic standard deviation were estimated by the maximum-likelihood method, as follows:

$$\mathrm{ASD} = \sqrt{\frac{\sum_i^1 (y_i - \hat{y}_i)^2}{n}}$$

where ASD is the asymptotic standard deviation; y_i the observed value; $\hat{y}_i$ the estimated value and n the number of observations.

In addition, to evaluate the adequacy of the chosen variables, a cross-validation (Efron and Tibshirani, 1998) was performed with 2000 simulations using the nonlinear least squares function of R (R Development Core Team, 2015) and the packages 'boot' and 'mass'. For each simulation, the original database was randomly divided into two new subsets, that were approximately of the same size. The first subset (training subset) was used to obtain the equations and the second subset (testing subset) was used to test the equations to obtain the adequacy statistics. After each simulation, the data set was reorganized, and the processes repeated 2000 times to take the average of the adequacy statistics.

These results were used to estimate the accuracy and precision of the developed equations through the mean square error of prediction (MSEP), concordance correlation coefficient (CCC), and R^2. The MSEP was decomposed in three main sources of variation: (1) mean bias, that represents a central tendency of deviation; (2) systematic bias, that represents the deviation of the slope from 1; and (3) random error, that represents the variation that is not explained by the regression (Tedeschi, 2006). The CCC was used to access, simultaneously, model accuracy and precision and was decomposed into correlation coefficient estimate (ρ) that estimates model precision and bias correction factor (C_b) that indicates accuracy. In addition, the location shift, scale shift, standard deviation of estimated CCC were calculated according to Lin (1989). Values of CCC, ρ and C_b ranging from 0 to 1, where values close to 1 indicate precise and/or accurate models (Lin, 1989; Tedeschi, 2006).

In addition, a bootstrap analysis was carried out to estimate the bias associated with each parameter estimate.

The bootstrap analysis consisted of building a pseudo-database by replicating and resampling the original database *n* times and summarizing the outcome (Davison *et al.*, 2003). We performed 2000 simulations to estimate the bias based on independent observations. The bootstrap analysis was also carried out using the software R (R Development Core Team, 2015) and the package 'boot' (Davison and Hinkley, 1997).

Results and discussion

The Pearson correlation coefficients of the different parameters associated with SFI are presented in Table 3. There was no correlation between SFI and birth BW or $BW_b^{0.75}$. The SFI was negatively correlated with MI, suggesting that SFI is lower when greater amounts of milk are offered, even after the first weeks of life (Hill *et al.*, 2010 and 2013; Miller-Cushon *et al.*, 2013a). In contrary, age was highly positively correlated with SFI, which is mainly due to gastrointestinal tract development, which increases SFI capacity with age and size (Silva *et al.*, 2015). Gelsinger *et al.* (2016), in a meta-analysis with treatment means of nine studies, reported a correlation of −0.82 between SFI and MI. According to the linear relationship those authors reported that an increase of 100 g in liquid feed DMI corresponded to a 66 g reduction in solid feed DMI. However, according to our results, an exponential relationship between SFI and MI was observed, which is also affected by animal age. In our case, an increase of 100 g in liquid feed DMI corresponds to a 13 g/day decrease in SFI for a calf 30 days old, and close to 93 g/day for a calf 60 days old.

Table 3 *Pearson's correlation coefficients between several factors and starter feed intake of preweaned dairy calves*

Variables	Coefficient of correlation	*P*-value
Milk intake (l/day)	−0.388	<0.001
Initial BW (kg)	0.014	0.301
Initial metabolic BW (kg)	0.015	0.238
Age (days)	0.660	<0.001
Fat intake (g/day)	−0.245	<0.001
CP intake (g/day)	0.075	<0.001
Metabolizable energy intake (Mcal/day)	0.057	<0.001

Besides MI and age, several other variables have been reported as potential influencers of SFI, such as performance (ADG), which has been associated with intake of growing heifers and finishing rams (Vieira *et al.*, 2013; Oliveira and Ferreira, 2016), the composition of starter feed (Kuehn *et al.*, 1994; Yavuz *et al.*, 2015) and the composition of liquid feed (primarily protein and fat content) (Hill *et al.*, 2008; Stamey *et al.*, 2012). The adverse effects of protein and fat intake on SFI are, primarily, due to changes in daily metabolizable energy intake (Hill *et al.*, 2008; Kertz and Loften, 2013). However, although statistically highly significant ($P < 0.001$), total daily protein and metabolizable energy intakes showed a very low positive association with SFI (Table 3), while daily fat intake presented a low negative correlation with SFI ($r = -0.24$; Table 3).

Nevertheless, it was not possible to include any of these variables in our model of SFI, because of the high correlation between them and MI. Because of the high correlation between MI and ADG (0.96), fat intake (0.84), protein intake (0.87) and metabolizable energy intake (0.89), only MI was retained in our model.

Effects of liquid feed source (milk or milk replacer) were not observed ($P > 0.05$) for any of the equation parameters (Figure 1a). The graphical dispersion of the standardized residual of SFI indicated the impossibility to use a single equation to predict SFI for all scenarios, as the single model under-predicted SFI for calves feeding <5 l/day of milk or milk replacer, and over-predicted SFI for calves feeding more than this amount of liquid feed (Figure 2). The distribution of the standardized residual SFI showed high variability for calves consuming <5 l/day of milk/milk replacer (Figure 2).

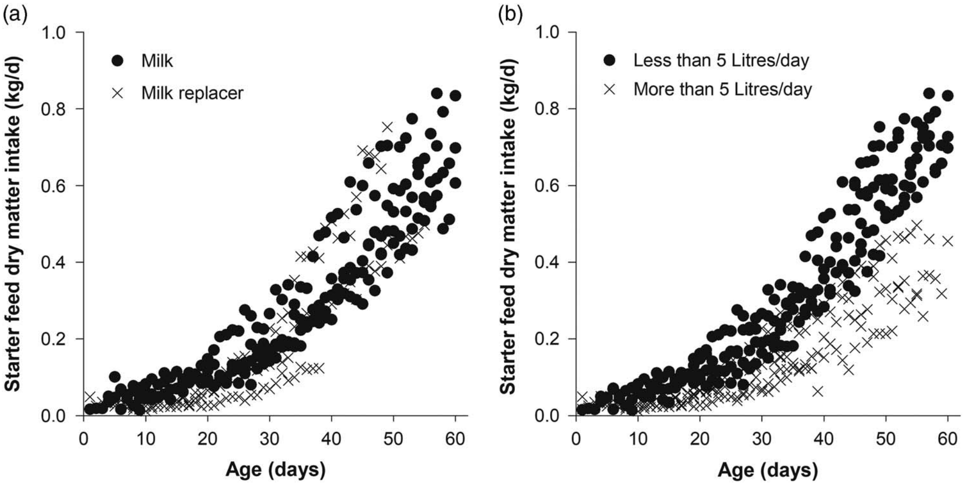

Figure 1 Average daily starter feed intake by experiments for preweaned dairy calves that received milk or milk replacer as liquid feed (a) and consuming less or more than 5 l/day of milk or milk replacer (b).

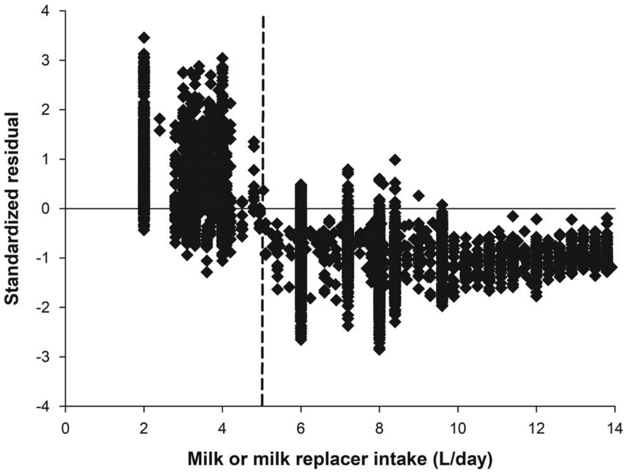

Figure 2 Graphical dispersion of standardized residual according to milk or milk replacer intake for a single model to predict starter feed intake for preweaned dairy calves.

A similar pattern was observed by Gelsinger *et al.* (2016), reporting greater variability in SFI for calves consuming <0.8 kg/day DM from liquid feed (around 6 l/day of fluid milk/milk replacer). Moreover, the different course of SFI over time between calves consuming less or more than 5 l/day of milk/milk replacer (Figure 1b) contributed to the impossibility to use a single model to predict SFI.

Therefore, two equations were developed to predict SFI for calves that receive <5 l/day ($\mathrm{SFI}_{<5}$) or >5 l/day ($\mathrm{SFI}_{>5}$) of milk/milk replacer, as follows ($\mathrm{Parameter}_{\pm\mathrm{SEM}}$):

$$\begin{aligned}\mathrm{SFI}_{<5} &= 0.1839_{\pm 0.0581} \times \mathrm{MI}\\ &\times \exp^{\left(\left(0.0333_{\pm 0.0021} - 0.0040_{\pm 0.0011} \times \mathrm{MI}\right) \times \left(A - \left(0.8302 \pm_{0.5092} + 6.0332_{\pm 0.3583} \times \mathrm{MI}\right)\right)\right)}\\ &-(0.12 \times \mathrm{MI});\end{aligned}$$

$$\begin{aligned}\mathrm{SFI}_{>5} &= 0.1225_{\pm 0.0005} \times \mathrm{MI}\\ &\times \exp^{\left(\left(0.0217_{\pm 0.0006} - 0.0015_{\pm 0.0001} \times \mathrm{MI}\right) \times \left(A - \left(3.5382 \pm_{1.3140} + 1.9508_{\pm 0.1710} \times \mathrm{MI}\right)\right)\right)}\\ &-(0.12 \times \mathrm{MI});\end{aligned}$$

where MI is the milk or milk replacer intake (l/day) and *A* the age (days).

The cross-validation analysis indicated a very high accuracy for both equations through the C_b values of 0.97 and 0.95 for $\mathrm{SFI}_{<5}$ and $\mathrm{SFI}_{>5}$, respectively (Table 4). In addition, the partition of MSEP indicated a low error of prediction directly associated with the fixed variables because the most of the error of prediction was associated with random errors (99.8% and 99.9% for $\mathrm{SFI}_{<5}$ and $\mathrm{SFI}_{>5}$, respectively).

In agreement with the cross-validation, small biases were observed with the bootstrap analyses (Table 5), indicating that variables were consistent and sufficient to predict SFI for both equations (Marcondes *et al.*, 2012). The equations presented a moderate precision with R^2 values of 0.61 and 0.52, and ρ values of 0.78 and 0.72, for $\mathrm{SFI}_{<5}$ and $\mathrm{SFI}_{>5}$, respectively, that yielded moderate to high CCC values (Table 4). The high accuracy demonstrated by the equations demonstrates their adequacy, as that is the most important measure of goodness of fit, and represents the model's ability to predict actual values (Tedeschi, 2006).

Table 4 *Adequacy parameters of the equations to predict starter feed intake (SFI) as obtained with the cross-validation technique*

Item	$\mathrm{SFI}_{<5}$	$\mathrm{SFI}_{>5}$
MSEP (kg × kg)	0.027	0.020
Partition of MSEP (%)		
Mean bias	0.08	0.03
Systematic bias	0.12	0.07
Random error	99.8	99.9
CCC (ranging from 0 to 1)	0.76	0.68
ρ	0.78	0.72
C_b	0.97	0.95
CCC		
SD	0.00026	0.00028
Location shift	0.908	0.753
Scale shift	−0.220	−0.148
P-value	<0.001	<0.001
R^2	0.61	0.52

MSEP = mean square error of prediction; CCC = concordance correlation coefficient; ρ = correlation coefficient estimate; C_b = bias correction factor; $\mathrm{SFI}_{<5}$ and $\mathrm{SFI}_{>5}$ = starter feed intake prediction for calves that receive <5 and >5 l/day of milk or milk replacer, respectively.

Table 5 *Parameters of the equations to predict starter feed intake (SFI) and their biases as estimated by bootstrap analysis*

	$\mathrm{SFI}_{<5}$		$\mathrm{SFI}_{>5}$	
Parameter	$\mathrm{Estimate}_{\pm\mathrm{SEM}}$	Bias	$\mathrm{Estimate}_{\pm\mathrm{SEM}}$	Bias
β_0	$0.1839_{\pm 0.0581}$	0.001378	$0.1255_{\pm 0.0005}$	0.000015
β_1	$-0.0040_{\pm 0.0011}$	0.000005	$-0.0015_{\pm 0.0001}$	−0.000003
β_2	$0.0333_{\pm 0.0021}$	−0.000039	$0.0217_{\pm 0.0006}$	0.000026
β_3	$6.0332_{\pm 0.3583}$	0.023892	$1.9508_{\pm 0.1710}$	0.004645
β_4	$0.8302_{\pm 0.5092}$	0.011961	$-3.5382_{\pm 1.3140}$	−0.016449

β_0, β_1, β_2, β_3 and β_4 = estimated parameters of the predictive equations; $\mathrm{SFI}_{<5}$ and $\mathrm{SFI}_{>5}$ = starter feed intake prediction for calves that receive <5 and >5 l/day of milk or milk replacer, respectively.

In conclusion, the SFI of dairy calves up to 64 days of age increases exponentially with age. The rate of increase is greater for calves consuming <5 l milk/day than for calves consuming more than 5 l milk/day, but is independent of the source of liquid feed. Overall, the results of the models' adequacy indicate that both models have great potential to predict SFI for suckling dairy calves, presenting moderate precision and very high accuracy. In addition, as diets and management of these animals are very similar across the world, the use of these models may be applied to most common rearing conditions. However, we highlight the necessity to conduct studies using a greater number of animals and studies, which may allow to evaluate other variables like sex and breed that were limited in our study.

Acknowledgments

The authors are grateful to those who originated the studies that were used in the database and for sharing data. Research conducted at the Universidade Federal de Viçosa were funded by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG) Instituto de Ciência e Tecnologia de Ciência Animal (INCT-CA). Research conducted at the University of Guelph was funded through a Natural Sciences and Engineering Research Council of Canada (NSERC, Ottawa, ON, Canada) Discovery Grant (T. J. DeVries).

Declaration of interest
None.

Ethics statement
None.

Software and data repository resources
None.

Supplementary material

To view supplementary material for this article, please visit https://doi.org/10.1017/S1751731118000666

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