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The relationship between feed efficiency and behaviour differs between lactating Holstein and Jersey cows

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Abstract

In dairy production, high feed efficiency (FE) is important to reduce feed costs and negative impacts of milk production on the climate and environment, yet little is known about the relationship between FE, eating behaviour and activity. This research communication describes how cows differing in FE, expressed as daily energy corrected milk production per unit of feed intake, differed in eating behaviour and activity. We used data from a study of 253 lactations obtained from 97 Holstein and 91 Jersey cows milked in an automatic milking system. Automated feed troughs recorded feed intake behaviour and cows wore a sensor that recorded activity from 5 to 200 d in milk (DIM). We used a mixed linear model to estimate random solutions for individual cows for traits of steps, lying and eating behaviour and calculated their correlation with FE during four periods (5–35, 36–75, 76–120 and 121–200 DIM). Separate analyses were performed for each breed and period. We found that individual level correlations between FE and behaviour traits were stronger in Jersey than in Holstein cows. Eating rate correlated weakly negatively to FE in Holstein cows and more strongly so in Jersey cows, such that efficient Jerseys were slower eaters. The physical activity of Jersey cows was weakly and negatively correlated to FE, but this was not the case in Holstein cows. We conclude that eating rate was consistently negatively associated with FE throughout lactation for Jersey cows, but not for Holstein cows.

Besides impacting dairy farmer profit, feed efficiency (FE) has become increasingly important due to the favourable link between FE and climate (Difford *et al*., 2020). Our study was driven by the question: which behavioural traits are associated with feed efficient cows? Even after adjusting for metabolic body weight and changes to live weight and body composition, large individual differences in FE remain between cows. Part of the explanation may be differing physical activity level (Olijhoek *et al*., 2020) or genetics (Hurley *et al*., 2017). Other traits, such as eating behaviour, have been related to FE (Connor *et al*., 2013; Ben Meir *et al*., 2018; Brown *et al*., 2022). Moreover, various behaviour traits showed large individual variation and demonstrated correlation with production traits (Munksgaard *et al*., 2020). Being a complex trait, FE might also be associated with cow behaviour at individual or breed level. Additionally, parity and lactation stage are known to affect both production traits, behaviour traits and their interactions (Munksgaard *et al*., 2020). We defined FE as the ratio between daily energy corrected milk production and dry matter intake (DMI), thus FE was kg ECM/kg DMI. We hypothesized FE to be related to key behaviour traits of eating and activity at the level of individual cows. To our knowledge, this is one of the first studies of correlations between lying behaviour and FE.

Materials and methods

Animals and housing

We used a dataset collected from 91 Jersey and 97 Holstein cows contributing 253 lactations (97 primiparous and 156 multiparous lactations) from February 2015 to February 2017. Details were reported by Henriksen *et al*. (2019). Briefly, cows were housed all-year around in two groups by breed at The Danish Cattle Research Centre (DCRC) at Aarhus University (Tjele, Denmark). Each group had free access to a milking robot (VMS, DeLaval International AB, Tumba, Sweden). Milk samples were collected during 48 h every week and analysed for fat, protein and lactose content. A scale in each robot recorded live weight at each milking. Cows were loose-housed with access to one cubicle/cow. Pelleted concentrate feed was offered in the robot according to one of two treatments; flat rate or individual strategy. Concentrate allowance was 3 kg/d for the flat rate treatment after the first 2 weeks, for the individual strategy it varied from 2 to 10 kg/d. All cows had ad libitum access to a partial mixed ration (PMR, concentrate:forage-ratio 35 : 65), including (as % of DM) corn silage (38.4), grass-clover silage (26.3), rapeseed cake (12.1), NaOH treated wheat (9.8), dried sugar beet pulp (7.9), soybean meal (3.5), and mineral-vitamins (2.0) offered in automated feed troughs (RIC system, Insentec B.V., Marknesse, The Netherlands). Fresh feed was delivered four times/d. Holstein cows had 27 available feed troughs (1.8 to 2.3 cows/trough), whereas Jersey cows had 25 feed troughs (1.9–2.6 cows/trough). A hind leg activity sensor (AfiTagII, AfiMilk, Israel) recorded lying time, lying bouts and number of steps. Leg sensors are generally considered non-invasive and are commonly used on commercial farms, therefore, an ethical approval was not needed according to European laws and current guidelines for the ethical use of animals in research.

Data processing

Calculation of daily lying time and feed intake of PMR was described by Munksgaard *et al.* (2020). The duration of each visit to a feed trough was summarised over a day to calculate eating time (min/d), and eating rate (g DMI/min eating) was defined as PMR intake (g DMI/d) divided by eating time (min eating/d). Eating visits was the number of times a cow entered and ate from a feeding trough. Milk yield was recorded by the robot, as described in Henriksen *et al.* (2019). ECM (3.14 MJ/kg) was calculated from milk yield and composition (Henriksen *et al.*, 2019). Calculation of daily live weights and data filtering were described by Munksgaard *et al.* (2020).

Statistical analysis

A linear mixed model (Eq. 1) (MIXED procedure, SAS ver. 9.4, SAS Institute Inc.) was used to describe variation in behavioural traits for each of four lactation periods in agreement with Munksgaard *et al.* (2020): DIM 5–35, DIM 36–75, DIM 76–120, and DIM 121–200.

$$y_{ijklm} = \mu + B_i + P_j + BP_{ij} + T_k + TB_{ik} + TP_{jk} + Y_l + M_m + \beta_1 W + \beta_2 \Delta W + C_{ijk} + \epsilon_{ijklm}, \quad (1)$$

where y_{ijklm} was the observed value of a trait, μ was the intercept, B was the effect of breed (i = Jersey, Holstein), P was the effect of parity group (j = primiparous, multiparous), BP was the interaction between B and P, T was the effect of treatment (k = flat rate, individual), TB and TP were the interactions between treatment and breed and parity, Y was effect of year ($l = 2015 : 2017$), M effect of month ($m = 1 : 12$), β_1 was the continuous effect of live weight W, β_2 the continuous effect of live weight change ΔW, C was the random effect of cow within parity, breed, and treatment, and ϵ the residual. The amount of variance attributable to individual cow effects was calculated as the repeatability coefficient from the variance components estimated in the model. Repeatability (t) was the ratio between animal variance and total random variance (Eq. 2).

$$t = \frac{\sigma^2_{\text{cow}}}{(\sigma^2_{\text{cow}} + \sigma^2_{\text{residual}})}, \quad (2)$$

The repeatability was an intra-class correlation, comparable to other correlations, expressing the correlation between repeated measurements of the given trait on the same individual.

An extended version of the model was used across lactation periods by including period and the interaction between breed, parity, and lactation period.

Individual level correlations between FE and behaviour traits were estimated as Pearson correlations between the random solutions from model 1 for each behavioural trait; lying time (min/d), lying bouts (no./d), steps (no./d), eating time (min/d), eating visits (no./d), and eating rate (g/min) within each period of lactation were estimated.

Results and discussion

Results showed that for FE, the interaction between breed, parity and lactation period was significant ($P < 0.001$, Table 1). FE declined within both breeds and parity groups as lactation progressed from the first to the third lactation period, whereas the decline in FE from third to fourth lactation period was smaller and only stayed significant for primiparous Jerseys and multiparous Holstein cows (Table 1). We observed no difference in FE between breeds for primiparous cows but multiparous Holstein cows were more feed efficient than Jersey cows during very early lactation, conversely, multiparous Holstein cows were less feed efficient than Jersey cows from 121 to 200 DIM. Within breed, multiparous Jersey cows were more feed efficient than primiparous Jersey cows only from 121 to 200 DIM, and multiparous Holstein cows were more feed efficient than primiparous Holstein cows from 5 to 120 DIM (Table 1).

Summarized across lactation, as also reported by Munksgaard and colleagues (2020), Holstein cows had higher milk yield, body weight and DMI as well as longer eating time than that of Jersey cows. The lying time of Holstein cows was on average 11% longer, and their activity (step/d) was on average 33% lower than that of Jersey cows. Further, eating rate was slowest in primiparous Jerseys, followed by primiparous Holsteins, multiparous Holsteins and fastest in multiparous Jersey cows. FE differed between the Jersey and Holstein cows, despite both breeds being housed and managed identically. According to Munksgaard *et al.* (2020), Jersey cows from 15 to 252 DIM at DCRC make more eating visits but have shorter eating time than Holstein cows. Additionally, younger Jersey cows have a lower eating rate than older Jersey cows and lactation stage affects eating rate, eating time, and number of eating visits. Ibn our study, FE ranged from 1.66 to 2.35 kg ECM/kg DMI across the two breeds investigated. The lower end of this range corresponds to the FE level in Holstein cows from 93 to 152 DIM (Xi *et al.*, 2016). Furthermore, FE declined within both breeds and parity groups as lactation progressed, except for multiparous Jerseys and primiparous Holstein, whose FE did not differ between 75–120 and 121–200 DIM.

Descriptive statistics for each behaviour trait were reported by breed and lactation period (Table S1). Repeatability of FE and the behaviour traits were all moderate to strong, varying from $t = 0.29$ to 0.90 and of similar magnitude in Holstein and Jersey cows (Table S2). Repeatability estimates from the four lactation periods were also rather similar within each trait, and all estimates had small standard errors. Individual differences in FE and behaviour traits account for a large proportion of the random variation in these traits, as shown by their moderate to strong repeatability. Repeatability estimates are considered the upper limit to

Table 1. Least-square means of feed efficiency (kg ECM[1]/kg DMI[2] ± SE[3]) of primiparous and multiparous Jersey and Holstein cows during four lactation periods, reported from the extended model including lactation period and interaction between breed, parity, and lactation period, adjusted for body weight, body weight change, and centred

	DIM[4]			
	5–35	36–75	76–120	121–200
Holstein				
Primiparous	2.00 ± 0.03^{ax}	1.79 ± 0.03^{bx}	1.67 ± 0.03^{cx}	1.66 ± 0.03^{cx}
Multiparous	2.35 ± 0.03^{ay}	1.97 ± 0.03^{bx}	1.81 ± 0.03^{cx}	1.68 ± 0.03^{dy}
Parity *P*-value	0.001	0.001	0.002	NS[5]
Jersey				
Primiparous	2.10 ± 0.05^{ax}	1.90 ± 0.05^{bx}	1.75 ± 0.05^{cx}	1.66 ± 0.05^{dx}
Multiparous	2.09 ± 0.03^{ax}	1.92 ± 0.03^{bx}	1.89 ± 0.03^{cx}	1.79 ± 0.03^{cx}
Parity *P*-value	NS	NS	NS	0.02

[a,b,c,d]Significant difference between lactation periods within breed and parity at $P < 0.05$; [x,y] Significant difference between breeds within parity and lactation period at $P < 0.05$; Parity *P*-values report differences between parities within breed and lactation period.
(1) ECM: energy corrected milk.
(2) DMI: dry matter intake.
(3) SE: standard error.
(4) DIM: days in milk.
(5) NS: not significant.

Table 2. Correlations (random solutions from mixed model) between feed efficiency and behaviour traits by lactation period and breed

	DIM			
	5–35	36–75	76–120	121–200
Holstein				
Number of lactations	114	114	96	84
Eating time	−0.08	−0.03	0.00	0.27*
Eating visits	0.04	−0.09	0.08	0.27*
Eating rate	−0.17	−0.02	0.10	−0.12
Steps	−0.04	−0.02	0.07	0.11
Jersey				
Number of lactations	94	109	97	82
Eating time	0.08	0.14	0.24*	0.29*
Eating visits	−0.18	−0.31***	−0.31**	−0.06
Eating rate	−0.47***	−0.52***	−0.64***	−0.47***
Steps	−0.24*	−0.16	−0.27**	−0.33*

Correlation significant at levels: *) 0.05; **) 0.01; ***) 0.001.

heritability, thus indicating that these traits are also heritable. FE is heritable (Difford *et al*., 2020), and genetic selection as a tool to improve FE is of key interest to dairy cattle breeding. Several feeding behaviour traits are highly repeatable, but studies on their heritability are still scarce (Løvendahl and Munksgaard, 2016).

The eating rate of Jerseys was negatively correlated with FE across all lactation periods from 5 to 200 DIM at the individual level, whereas for Holsteins this correlation was close to zero (Table 2). In a study on 453 mixed parity Holstein cows during the first 90 DIM, high FE was associated with slower eating rate (Connor *et al*., 2013). Likewise, high yielding Holstein cows from 35 to 180 DIM decrease their eating rate with increasing FE (Ben Meir *et al*., 2018). Moreover, the residual feed intake (RFI) of mid-lactation Holstein cows correlates positively with eating rate (Brown *et al*., 2022). Contradictory results among studies may arise from utilising different diets, definitions of eating behaviours, lactation stages, and feed trough stocking density. Thus, feed trough stocking density may affect eating rate, as competition for feed reduces average meal duration and increases eating rate (Llonch *et al*., 2018). However, our study did not enable us to conclude by how much stocking density affects feeding behaviour.

Eating time correlated positively with FE during 121–200 DIM for Holsteins and during 76–200 DIM for Jerseys (Table 2). Conversely, in another large study high FE is associated with

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less time eating per day during 1–90 DIM (Connor *et al.*, 2013). The number of eating visits correlated positively with FE from 121 to 200 DIM for Holsteins and from 76 to 200 for Jerseys. The number of steps (activity) was negatively correlated with FE from 5 to 35 and again from 76 to 200 DIM for Jerseys. By contrast, steps showed no correlation with FE for the Holstein cows. Lying time and number of lying bouts showed no significant correlation with FE at any time and were omitted from Table 2. Others observe a positive correlation between activity and RFI (Connor *et al.*, 2013), i.e., FE decreases with increasing activity due to the inverse relationship between RFI and FE. Other factors may affect eating behaviour and FE, for instance higher lactation persistency in primiparous cows, feed intake, and energy balance.

In conclusion, our results partly supported our hypothesis that FE was related to eating behaviour traits. Thus, eating rate was consistently negatively associated with FE throughout lactation for Jersey cows, but not for Holstein cows. Our hypothesis of a relationship between FE and traits of lying behaviour was not supported by our results. We encourage future studies designed to elucidate the relationships between FE and eating behaviour in greater detail.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S0022029923000420.

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