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Association of Feed Efficiency, Feeding Rate, and Behaviour with the Milk Performance of Dairy Cows

Lenka Krpálková [1,*], Niall O'Mahony [1], Anderson Carvalho [1], Sean Campbell [1], Gerard Corkery [2], Eilish Broderick [2], Daniel Riordan [1] and Joseph Walsh [1]

[1] Lero—The Irish Software Research Centre, Department of Agricultural and Manufacturing Engineering, School of Science Technology Engineering and Maths (STEM), Kerry Campus, Munster Technological University, V92 CX88 Tralee, Ireland; niall.omahony@mtu.ie (N.O.); Anderson.Carvalho@mtu.ie (A.C.); Sean.Campbell@staff.ittralee.ie (S.C.); daniel.riordan@mtu.ie (D.R.); joseph.walsh@mtu.ie (J.W.)

[2] Department of Biological & Pharmaceutical Science, School of Science Technology Engineering and Maths (STEM), Kerry Campus, Munster Technological University, V92 CX88 Tralee, Ireland; Gerard.Corkery@mtu.ie (G.C.); eilish.broderick@mtu.ie (E.B.)

* Correspondence: lenka.krpakova@mtu.ie

Abstract: Identification of the associations of cow feed efficiency with feeding behaviour and milk production is important for supporting recommendations of strategies that optimise milk yield. The objective of this study was to identify associations between measures of feed efficiency, feed intake, feeding rate, rumination time, feeding time, and milk production using data collected from 26 dairy cows during a 3 month period in 2018. Cows averaged (mean ± standard deviation) 2.2 ± 1.7 lactations, 128 ± 40 days in milk, 27.5 ± 5.5 kg/day milk, 1.95 ± 0.69 kg feed/1 kg milk—the measure used to express feed conversion ratio (FCR), 575 ± 72 min/day rumination time, and 264 ± 67 min/day feeding time during the observation period. The coefficient of variation for rumination time (min/d) was 12.5%. A mixed linear model was selected for analyses. The most feed inefficient cows with the highest FCR (≥2.6 kg feed/1 kg milk) showed the lowest milk yield (24.8 kg/day), highest feed intake (78.8 kg), highest feeding rate (0.26 kg/min) and BCS (3.35 point). However, the relative milk yield (milk yield per 100 kg of body weight) was the highest (4.01 kg/day) in the most efficient group with the lowest FCR (≤1.4 kg feed/1 kg milk). Our study showed that the most efficient cows with the lowest FCR (≤1.4 kg feed/1 kg milk) had the highest rumination time (597 min/day; $p < 0.05$), feeding time (298 min/day; $p < 0.05$), rumination/activity ratio (4.39; $p < 0.05$) and rumination/feeding ratio (2.04; $p < 0.05$). Less active cows (activity time 164 min/day; $p < 0.05$) were the most efficient cows with the lowest FCR (≤1.4 kg feed/1 kg milk). The behavioural differences observed in this study provide new insight into the association of feed behaviour and feed efficiency with milk performance. Incorporating feeding behaviour into the dry matter intake model can improve its accuracy in the future and benefit breeding programmes.

Keywords: body weight; body condition score; gross feed efficiency; relative milk yield; rumination

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1. Introduction

In a dairy business, feed costs are typically the largest cost category, accounting for approximately 40% of total costs of production in Ireland [1]. Monitoring feed efficiency in the dairy industry has not been used as a common benchmark for monitoring the profitability and efficiency of converting nutrients to milk yield. The "traditional assumption" was that cows consume more feed to support higher milk production, and the amount of digested nutrients captured as milk is proportionately higher [2]. However, a cow that produces more milk with greater feed efficiency is even more profitable [1].

This hypothesis has spurred research into breeding animals that use feed more efficiently, thereby reducing feed costs per unit of milk [2–5]. A universal definition of feed efficiency does not exist and multiple measures can be used to describe how efficiently animals convert feed into products [5]. Genomics also enables selection for new traits, such as feed efficiency [2]. Systems for classifying efficient and inefficient cows in commercial farms are under development [6,7].

Beyond the genetic merit of such systems, farm applications depend on dietary and environmental management—how to fit dry matter intake and environmental conditions to a known feed efficiency of the target animal [8]. Eventually, management practices might be tailored specifically for genotypes or genotypes might be selected to match environments [2]. Individual cattle can vary in dry matter intake and feed efficiency but they can also differ in the amount of manure, methane, and carbon dioxide they produce for a given unit of dry matter intake, and in their ability to generate and conserve heat energy [9,10].

According to Clément et al., rumination time, which is already recorded in commercial dairy herds by a sensor-based system, has been suggested as a potential dry matter intake indicator [11]. However, in a study by Byskov et al. [12], rumination time was not found to be a suitable indicator trait for dry matter intake and only a weak indicator of feed efficiency. Beauchemin concluded that there are complex interactions among these factors; thus, the correlation between rumination time and individual dietary factors is only low to moderate [13].

Identification of the associations of cow feeding behaviour with productivity and environmental conditions is important for supporting recommendations of strategies that optimise milk yield and composition [14]. In fact, some authors were already able to identify a positive association between milk production and rumination time [15–18]; genetic improvement of dairy cattle is now occurring faster than at any time in history due to the genomic approach. Undesirable side effects from intense selection for feeding efficiency may occur. It means that it is important to carefully consider the approach used for improving feed efficiency of dairy cows [19].

Dairy cows have certain biological limits and any disruption of animal welfare can lead to its impairment and negatively affect the health and productivity of animals [1]. The property of "robustness" resides in the dairy cow genome. Robustness is the ability to face environmental constraints and combines high production potential with resilience to stress factors (e.g., heat stress), allowing for stable, high production in a wide variety of conditions [20]. Genomic selection can be a supplementary strategy with cumulative and permanent effects. It implies that heat tolerance, feed efficiency, and feeding behaviour, should be included in a multi-trait selection index, correlated with other production and functional traits and finally net economic effect [21].

Smart machines and sensors are improving and changing rapidly; however, available data for feed efficiency are very limited due to the high cost and difficulty in collecting individual feed intake records. Moreover, none of the existing feed intake models incorporate individual feeding behaviour into the feed intake evaluation formula. Therefore, in this study, we aimed to evaluate the association of gross feed efficiency or FCR (the total weight of feed divided by net milk production), feed intake, and feeding rate with feeding behaviour (i.e., feeding, rumination time, and ratio), milk yield, and relative milk yield (milk yield per 100 kg of body weight).

2. Materials and Methods

The data were collected from one experimental dairy farm over a 3 month period (May to July) during 2018. The Holstein dairy cows involved in this study were raised in a free-stall barn located in Ireland. The data set observed in this study consisted of 26 dairy cows and the number of lactations ranged from 1 to 6 (first lactation, $n = 10$; second lactation, $n = 10$; $\geq$third lactation, $n = 6$; where n denotes the number of cows in the dataset). All were monitored for daily milk yield, behaviour (i.e., rumination, feeding, resting and activity time (min)), feed intake (kg), and body weight (kg). The farms' records of body condition score (BCS) were collected every 3 weeks and missing values were replaced with the closest observation. For each cow, BCS was assessed by at least two persons who had learned the BCS evaluation technique from a veterinarian. All cows were on a TMR diet (a mixture of forage and grain) for the full 24 h/day. The TMR had lower dry matter content (20–25%) in the first 1.5 months and higher (35–40%) in the last 1.5 months of the evaluated period. The sample size for cows $\geq$ 3rd lactation was less due to the reduced availability of cows in that age range in the herd being evaluated. The sample sizes were chosen to ensure a representative dataset of a range of ages and the analysis was performed on the dataset (n = 26) in its entirety.

The participating farms milked 2× daily and the MY of each milking (Weighall Milk Meter, Dairymaster, Co., Kerry, Ireland) was recorded daily from 31 to 209 days in milk (DIM). Milk weights for the morning and afternoon milkings were summed to obtain daily milk yield; if data were missing at any milking due to technical problems, the milk yield for that day was reported as a missing value and was removed.

The behaviour was measured using the behaviour-monitoring collar (MooMonitor+, Dairymaster, Co., Kerry, Ireland) of each animal 24 h/d. The MooMonitor+ recording system stores information every minute and then summarise this data into rumination, feeding, resting, and activity time on an hourly basis. In order to ensure that the total times recorded for each behaviour were representative of the actual proportion of time spent in each throughout the day, only complete daily records were included in the dataset. If, due to technical problems, not all the information recorded by the collar was collected at the base station and the sum of all the behaviour records per cow per day was less than 1440 min (60 min × 24 h), the recording for that cow day was reported as a missing value and was removed from the dataset.

Dairymaster's MooMonitor+ is the first system validated in both indoor [22] and outdoor [23] systems. The neck-mounted device can detect bolus exchanges and records it as rumination activity with a coefficient of variation of 12.5%. Rumination is defined as the regurgitation and remastication of a bolus with a rhythmic jaw movement. A break between bolus exchanges of $\geq$5 s was recorded as a different activity. Feeding time was defined as when a cow's muzzle was in contact with feed, including sorting, smelling, and chewing feed (not stopping for $\geq$5 s). Feeding behaviour was recorded with a coefficient of variation of 25.3%.

Milk yield and behaviour data were obtained using Milk Manager Software (Dairymaster, Co., Kerry, Ireland) at the end of the trial.

The Insentec (Insentec, Marknesse, the Netherlands) monitoring system was used to collect continuous feeding data (feed intake). Radio frequency identification (RFID) was used to monitor individual cows regarding their feed intake and body weight. Developing a metric that includes all relevant factors for feed efficiency has proven challenging. Metrics for feed efficiency have been developed for feed and product mass (e.g., feed conversion efficiency per 1 kg milk) and feed and product economic value (e.g., income over feed cost); energy is generally the nutrient that limits milk production [2]. In the present study, we focused on gross energy and gross feed efficiency (FCR). Gross energy is the total chemical energy of a feed—not all gross energy is useful because some of it is lost in faeces, gasses, urine, and as metabolic heat while fermenting, digesting, and processing nutrients. Net energy is the remaining chemical energy used to support maintenance functions, milk secretion, or the accretion of body tissue and conceptus (for reproduction) [2]. More in-depth reviews can be found in the literature [24]. Gross feed efficiency is defined as the energy captured in products divided by the gross energy consumed by a cow. Gross feed efficiency does not consider the source or cost of feed energy, nor the composition and value of the products and can be used as an informative value for feed efficiency. However, gross feed efficiency is not very useful in making decisions about the nutrition management of dairy herds [2].

3. Statistical Analyses

The final dataset comprised 1895 daily milking records. Prior to analysis, all data were screened for normality and outliers using the UNIVARIATE procedure of SAS software [25].

Outliers (defined as those values > 1.5 times the interquartile range above the third quartile or below the first quartile) were detected and excluded from the analyses. All daily measures that satisfied the criteria are shown in Table 1.

Table 1. Evaluated parameters (dependent variables).

Item	Num. Records	Mean	SD	Minimum	Maximum
Milk yield, kg/d	1895	27.5	5.5	13.5	43.1
Relative milk yield [1], kg/d	1643	4.37	0.77	2.30	6.80
Lactations, n	1895	2.2	1.7	1	6
Days in milk, d	1895	128	40	31	209
Feed intake [2], kg/d	1895	52.9	19.9	11.8	125.1
Body weight, kg	1643	633	61	501	802
Body condition score, point	1895	2.94	0.40	2.25	4.00
Feeding rate, min/kg	1895	0.21	0.06	0.07	0.40
FCR [3], kg feed/1 kg milk	1895	1.95	0.69	0.72	4.00
Ruminating time [2], min/d	1895	575	72	231	787
Feeding time [2], min/d	1895	264	67	106	500
Resting time, min/d	1895	417	84	179	834
Activity time, min/d	1895	184	60	34	299
Rumination/activity ratio	1895	3.62	1.77	1.26	16.98
Rumination/feeding ratio	1895	2.35	0.79	0.72	6.89

[1] Relative milk yield = milk yield per 100 kg of body weight. [2] Correlation coefficient between rumination time and feeding intake = −0.25 ($p < 0.001$) and rumination time and feeding time = −0.10 ($p < 0.001$). [3] FCR = feed conversion efficiency per 1 kg milk (gross feed efficiency).

The MIXED procedure of SAS software [25] (i.e., applying a mixture of general linear models with fixed and random effects) was used, treating the animal as a random effect. All considered effects were statistically significant ($p < 0.05$, Equation (1)). Tukey's test was used to determined significant differences among means [26].

$$y_{ijklmn} = \mu + D_i + M_j + P_k + B_l + Z_m + e_{ijklmn} \quad (1)$$

where y_{ijklmn} = value of the dependent variable (listed in Tables 1–4); μ = the overall mean; D_i = the effect of the ith stage of lactation on the evaluated day (the lactation period was split into six parts, i = 1: 31 to 56 DIM, 2: 57 to 84 DIM, 3: 85 to 112 DIM, 4: 113 to 140 DIM, 5: 141 to 168 DIM, 6: 169 to 209 DIM), M_j = the effect of the jth month of the evaluated day (j = May, June, July), P_k = the effect of the kth parity (l = 1, 2, ≥3), B_l = effect of lth milk yield, relative milk yield, feeding rate, FCR, and feed intake class (Tables 2–4), Z_m = the effect of the nth cow (m = cows within farm, random effect); e_{ijklmn} = random error.

Pearson correlation using the CORR procedure of SAS software [25] was used to assess the relationship between the rumination time and feeding time and feed intake (Table 1).

Table 2. Effects of milk yield and relative milk yield [1] on evaluated variables.

Item	Milk Yield (kg/d)			Relative Milk Yield (kg/d)		
	≥31	**30 to 25**	**≤24**	**≥5**	**4.9 to 4**	**≤4**
***n* (Daily Measures)**	**517**	**710**	**668**	**382**	**760**	**501**
Milk yield, kg/d	-	-	-	31.6 ± 0.3 [a]	26.8 ± 0.3 [b]	22.7 ± 0.3 [c]
Relative milk yield [1], kg/d	4.81 ± 0.05 [a]	4.03 ± 0.05 [b]	3.30 ± 0.05 [c]	-	-	-
Feed intake, kg/d	76.9 ± 2.4 [a]	66.5 ± 2.1 [b]	55.0 ± 2.1 [c]	70.2 ± 2.4 [a]	65.0 ± 2.2 [b]	58.3 ± 2.1 [c]
Bodyweight, kg	687 ± 6 [a]	667 ± 5 [b]	661 ± 5 [c]	635 ± 5 [c]	652 ± 5 [b]	670 ± 5 [a]
Body condition score, point	3.16 ± 0.04 [c]	3.22 ± 0.04 [b]	3.51 ± 0.04 [a]	3.01 ± 0.04 [c]	3.17 ± 0.03 [b]	3.46 ± 0.03 [a]
Feeding rate, min/kg	0.26 ± 0.01 [a]	0.24 ± 0.01 [b]	0.21 ± 0.01 [c]	0.25 ± 0.01 [a]	0.24 ± 0.01 [a]	0.22 ± 0.01 [b]
FCR [2], kg feed/1 kg milk	2.44 ± 0.09	2.48 ± 0.08	2.42 ± 0.08	2.27 ± 0.08 [c]	2.37 ± 0.08 [b]	2.44 ± 0.08 [a]
Ruminating time, min/d	578 ± 10 [a]	563 ± 9 [b]	577 ± 9 [a]	568 ± 9	566 ± 9	563 ± 8
Feeding time, min/d	241 ± 9 [c]	288 ± 8 [b]	291 ± 8 [a]	244 ± 8 [b]	280 ± 8 [b]	288 ± 8 [a]
Resting time, min/d	390 ± 11 [a]	370 ± 10 [b]	391 ± 10 [a]	382 ± 11 [ab]	371 ± 10 [b]	398 ± 10 [a]
Activity time, min/d	233 ± 8 [a]	219 ± 7 [b]	180 ± 7 [c]	246 ± 7 [a]	223 ± 7 [b]	191 ± 7 [c]

Table 2. *Cont.*

Item	Milk Yield (kg/d)			Relative Milk Yield (kg/d)		
	≥31	30 to 25	≤24	≥5	4.9 to 4	≤4
***n* (Daily Measures)**	**517**	**710**	**668**	**382**	**760**	**501**
Rumination/activity ratio	2.96 ± 0.23 [c]	3.01 ± 0.20 [b]	4.03 ± 0.21 [a]	2.51 ± 0.22 [c]	3.04 ± 0.20 [b]	3.65 ± 0.20 [a]
Rumination/feeding ratio	2.48 ± 0.10 [a]	1.99 ± 0.09 [b]	1.99 ± 0.09 [b]	2.40 ± 0.10 [a]	2.07 ± 0.09 [b]	1.95 ± 0.09 [c]

[a–c] Within a row, mean values related to the same explanatory variable with different superscript letters are significantly different ($p < 0.05$).
[1] Relative milk yield = milk yield per 100 kg of body weight. [2] FCR = feed conversion efficiency per 1 kg milk (gross feed efficiency).

Table 3. Effects of feed intake on evaluated variables.

Item	Feed Intake, kg/day				
	≥80	79 to 60	59 to 40	39 to 30	≤29
***n* (Daily Measures)**	**236**	**419**	**606**	**519**	**115**
Milk yield, kg/d	26.8 ± 0.4 [a]	25.5 ± 0.4 [b]	24.5 ± 0.4 [c]	23.2 ± 0.4 [d]	21.3 ± 0.5 [e]
Relative milk yield [1], kg/d	3.95 ± 0.07 [a]	3.85 ± 0.07 [ab]	3.78 ± 0.07 [b]	3.65 ± 0.07 [c]	3.43 ± 0.09 [d]
Feed intake, kg/d	-	-	-	-	-
Bodyweight, kg	687 ± 5 [a]	672 ± 5 [b]	658 ± 5 [c]	643 ± 5 [d]	623 ± 6 [e]
Body condition score, point	3.30 ± 0.04 [b]	3.31 ± 0.04 [b]	3.30 ± 0.04 [b]	3.36 ± 0.04 [ab]	3.43 ± 0.05 [a]
Feeding rate, min/kg	0.28 ± 0.01 [a]	0.24 ±0.01 [b]	0.19 ± 0.01 [c]	0.18 ± 0.01 [d]	0.16 ±0.01 [e]
FCR [2], kg feed/1 kg milk	3.26 ± 0.04 [a]	2.72 ± 0.04 [b]	2.08 ± 0.04 [c]	1.58 ± 0.04 [d]	1.33 ±0.05 [e]
Ruminating time, min/d	539 ± 9 [d]	556 ± 9 [c]	588 ± 8 [b]	608 ± 9 [a]	569 ± 10 [c]
Feeding time, min/d	274 ± 8 [b]	274 ± 8 [b]	296 ± 8 [a]	305 ± 8 [a]	300 ± 10 [a]
Resting time, min/d	387 ± 10 [d]	383 ± 10 [c]	361 ± 10 [b]	371 ± 10 [a]	426 ± 12 [a]
Activity time, min/d	240 ± 7 [a]	226 ± 7 [b]	195 ± 7 [c]	156 ± 7 [d]	145 ± 8 [d]
Rumination/activity ratio	2.49 ± 0.20 [d]	2.86 ± 0.20 [c]	3.63 ± 0.20 [b]	4.71 ± 0.20 [a]	4.65 ± 0.24 [a]
Rumination/feeding ratio	1.97 ± 0.10	2.07 ± 0.10	1.97 ± 0.10	2.04 ± 0.10	1.87 ± 0.12

[a–e] Within a row, mean values related to the same explanatory variable with different superscript letters are significantly different ($p < 0.05$).
[1] Relative milk yield = milk yield per 100 kg of body weight. [2] FCR = feed conversion efficiency per 1 kg milk (gross feed efficiency).

Table 4. Effects of feeding rate and FCR on evaluated variables.

Item	FCR, kg Feed/1 kg Milk			Feeding Rate, min/kg		
	≤1.4	1.4 to 2.6	≥2.6	≥0.14	0.14 to 0.26	≥0.26
***n* (Daily Measures)**	**383**	**383**	**383**	**383**	**925**	**587**
Milk yield, kg/d	24.8 ± 0.4 [a]	25.3 ± 0.4 [b]	25.1 ± 0.4 [ab]	26.1 ± 0.4 [a]	24.8 ± 0.4 [b]	23.6 ± 0.4 [c]
Relative milk yield [1], kg/d	3.77 ± 0.07 [c]	3.92 ± 0.07 [b]	4.01 ± 0.07 [a]	3.99 ± 0.07 [a]	3.85 ± 0.07 [b]	3.67 ± 0.07 [c]
Feed intake, kg/d	78.8 ± 1.3 [a]	52.5 ± 1.3 [b]	33.7 ± 1.4 [c]	76.3 ± 2.0 [a]	57.5 ± 1.9 [b]	45.9 ± 2.1 [c]
Bodyweight, kg	24.8 ± 0.4 [a]	25.3 ± 0.4 [b]	25.1 ± 0.4 [ab]	673 ± 5 [a]	654 ± 5 [b]	650 ± 6 [b]
Body condition score, point	3.35 ± 0.04 [a]	3.31 ± 0.04 [ab]	3.29 ± 0.04 [b]	3.33 ± 0.04 [a]	3.33 ± 0.04 [a]	3.25 ± 0.04 [b]
Feeding rate, min/kg	0.26 ± 0.01 [a]	0.21 ± 0.01 [b]	0.18 ± 0.01 [c]	-	-	-
FCR [2], kg feed/1 kg milk	-	-	-	2.86 ± 0.07 [a]	2.31 ± 0.07 [b]	1.93 ± 0.07 [c]
Ruminating time [1], min/d	540 ± 8 [c]	582 ± 8 [b]	597 ± 8 [a]	548 ± 9 [c]	571 ± 8 [b]	587 ± 9 [a]
Feeding time, min/d	282 ± 8 [b]	287 ± 8 [b]	298 ± 8 [a]	272 ± 8 [b]	288 ± 8 [b]	312 ± 8 [a]
Resting time, min/d	387 ± 10 [a]	373 ± 10 [b]	381 ± 10 [ab]	398 ± 10 [a]	375 ± 10 [b]	350 ± 11 [c]
Activity time, min/d	230 ± 7 [a]	197 ± 7 [b]	164 ± 7 [c]	222 ± 7 [a]	205 ± 7 [b]	191 ± 8 [c]
Rumination/activity ratio	2.64 ± 0.20 [c]	3.63 ± 0.20 [b]	4.39 ± 0.21 [a]	2.92 ± 0.21 [a]	3.40 ± 0.21 [b]	3.64 ± 0.22 [b]
Rumination/feeding ratio	1.90 ± 0.10 [b]	2.06 ± 0.09 [a]	2.04 ± 0.10 [a]	2.06 ± 0.10 [a]	1.99 ± 0.09 [a]	1.83 ± 0.10 [b]

[a–c] Within a row, mean values related to the same explanatory variable with different superscript letters are significantly different ($p < 0.05$).
[1] Relative milk yield = milk yield per 100 kg of body weight. [2] FCR = feed conversion efficiency per 1 kg milk (gross feed efficiency).

Figures 1 and 2 were created with R 4.0.5. (Plotly package [27]). Only daily measurements with milk yield ≥ 30 kg/day were selected for Figures 1 and 2.

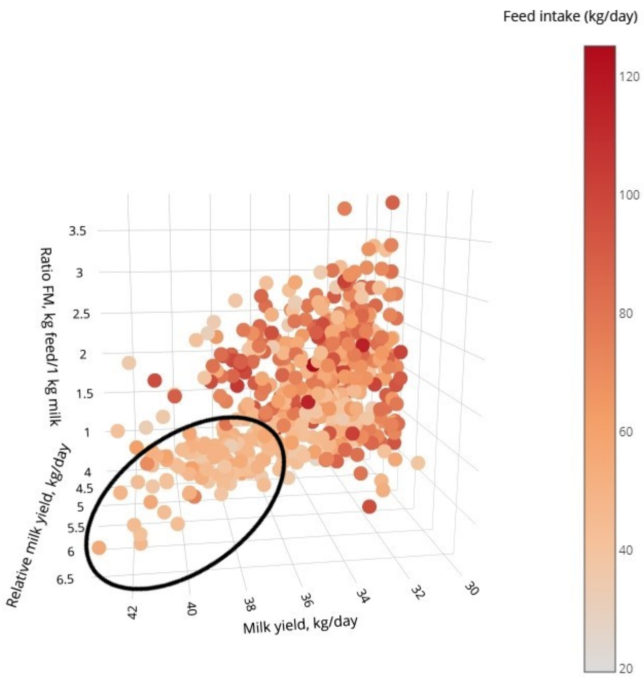

Figure 1. Association of milk yield, relative milk yield (milk yield per 100 kg of body weight), and FCR (feed conversion efficiency per 1 kg milk) in the range of 31 to 209 days in milk and milk yield ≥ 30 kg/day; milk yield: mean ± SD = 34.5 ± 3.1 kg/d, relative milk yield: mean ± SD = 5.14 ± 0.55 kg/d, FCR: mean ± SD = 1.80 ± 0.62 kg feed/1 kg milk; the black circle includes the highest yielding and feed efficient cows.

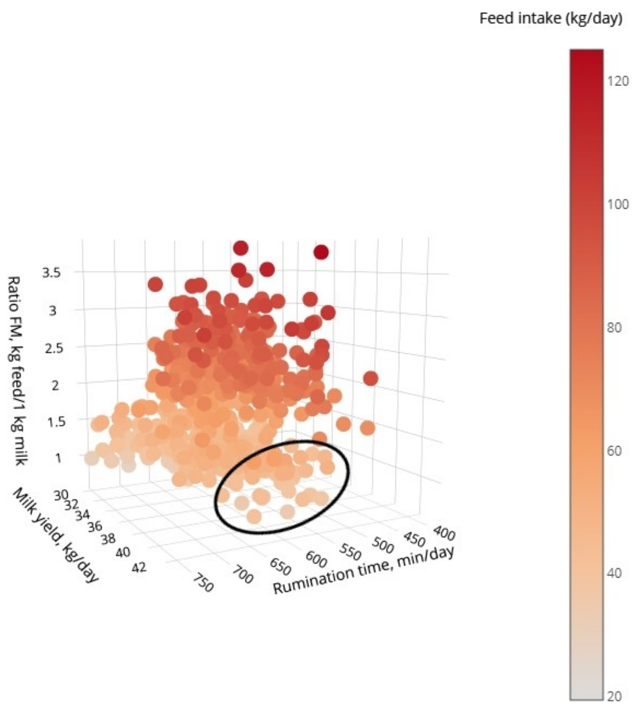

Figure 2. Association of milk yield, rumination time, and FCR (feed conversion efficiency per 1 kg milk) in the range of 31 to 209 days in milk and milk yield ≥ 30 kg/day; milk yield: mean ± SD = 34.5 ± 3.1 kg/d, rumination time: mean ± SD = 588 ± 65 min/d, FCR: mean ± SD = 1.80 ± 0.62 kg feed/1 kg milk; the black circle includes the highest yielding and feed efficient cows.

4. Results and Discussion

This study recorded the feed efficiency, behaviour, and productivity of lactating dairy cows. Table 1 provides an overview of the descriptive results of the examined traits. Figures 1 and 2 show the level of the examined traits for each daily measurement with milk yield $\geq$ 30 kg/day.

4.1. Milk Yield and Feed Traits

The highest feed intake (76.9 kg; $p < 0.05$), feeding rate (0.26 kg/min; $p < 0.05$), body weight (687 kg; $p < 0.05$), activity time (233 min/day; $p < 0.05$) and rumination/feeding ratio (2.48; $p < 0.05$) occurred in the group with the highest milk yield ($\geq$31 kg/day; Table 2). Similar results were found in relative milk yield for feed intake, and rumination/feeding ratio (Table 2), whereas the highest body weight (670 kg; $p < 0.05$) and lowest FCR (2.44 kg feed/1 kg milk; $p < 0.05$) were found in the group with the lowest relative milk yield ($\leq$4 kg/day). Body weight measurement is important because it is a major determinant of a cow's maintenance requirement. According to McNamara, net energy requirements vary by 20% among cows with similar levels of milk production [28]. However, recent evidence suggests that the maintenance requirement per unit of metabolic body weight has increased over time for dairy cattle as we have selected dairy cattle that require more feed per unit of metabolic bodyweight just to survive, and dairy cattle now seem to require ~10% more net energy for maintenance [29]. Based on these findings [2] suggest that any "maintenance" costs that are associated with higher milk production should be assigned to production and not maintenance.

The highest BCS (3.51 point; $p < 0.05$) and feeding time (291 min/day; $p < 0.05$) in the lactation (Table 2) occurred in the group with the lowest milk yield ($\leq$24 kg/day). BCS may alter the energy content of body weight change [2].

The differences between the highest ($\geq$5 kg/day) and lowest relative milk yield ($\leq$3.9 kg/day) in feed intake and FCR were 11.9 kg/day per cow ($p < 0.05$) and 0.17 kg feed/1 kg milk, respectively. The differences between the highest ($\geq$31 kg/day) and lowest milk yield ($\leq$24 kg/day) in feed intake were 21.9 kg/day per cow ($p < 0.05$). However, in the groups categorised according to their milk yield no significant differences in FCR were found as we expected, due to the mixed feeding of efficient and inefficient cows regardless of bodyweight in these groups (Table 2). Figure 1 includes observations where milk yield was more than 30 kg/day. The most feed efficient cows with the highest relative milk yield and lowest FCR are shown in the black circle. According to Ben Meir et al., feed inefficient cows consume dry matter and digestible energy beyond their energy needs that lead to excess energy losses and reduced feed efficiency [8]. Our study can confirm these findings, since activity time (240 kg min/day; $p < 0.05$) was the highest in the high feed intake group ($\geq$80 kg/day; Table 3). In this group were mostly feed inefficient cows because the most inefficient cows with the highest FCR ($\geq$2.6 kg feed/1 kg milk) achieved the highest activity time (230 kg min/day; $p < 0.05$) as well (Table 4).

The highest milk yield (26.8 kg/day; $p < 0.05$), relative milk yield (3.95 kg/day; $p < 0.05$), feeding rate (0.28 kg/min; $p < 0.05$), FCR (3.26 kg feed/1 kg milk; $p < 0.05$), and body weight (687 kg; $p < 0.05$), were found in the highest feed intake group ($\geq$80 kg/day; Table 3). The differences of the milk yield, relative milk yield, feeding rate, and FCR between high feed intake ($\geq$80 kg/day) and low feed intake ($\leq$29 kg/day) were 5.5 kg/day, 0.52 kg/day, 0.12 kg/min, and 1.93 kg feed/1 kg milk, respectively (Table 3). A study by Moraes et al., showed that feed intake increases relative to body size. Feed efficiency increases with body size, generally reaching a limit of 35 to 40% which varies among cows [29]. Beauchemin reported that there is no doubt that bigger cows have higher feed intake, moreover, cows can modify their feeding behaviour to consume feed in a shorter period when necessary and maintain feed intake, which can negatively affect the productivity of subordinate cows due to increased competition [13]. The cows with the highest feeding rate ($\leq$0.26 kg/min) also had the highest milk yield (26.1 kg/day), relative milk yield (3.99 kg/day), feed intake (76.3 kg), FCR (2.86 kg feed/1 kg milk), and

BCS (3.33 point; Table 4). Similar results were also demonstrated by the analysis of FCR, where the most inefficient cows with the highest FCR (≥2.6 kg feed/1 kg milk) showed the lowest milk yield (24.8 kg/day), highest feed intake (78.8 kg), highest feeding rate (0.26 kg/min), and BCS (3.35 point; Table 4). However, the relative milk yield (4.01 kg/day) was the highest in the most efficient group with the lowest FCR (≤1.4 kg feed/1 kg milk). Differences among cows in feed efficiency are mostly influenced by dry matter intake rather than milk production and body weight change [30,31]. Ben Meir et al. reported that feed inefficient cows differ from efficient cows fed the same (31.4% roughage) TMR by having a dry matter intake that is 25% higher owing to a 23% faster feeding rate and 23% larger meal size, although energy corrected milk yield of inefficient and efficient cows remained similar [8].

According to VandeHaar et al., high-producing herds have mostly already diluted out maintenance, i.e., a greater portion of the feed is partitioned toward milk instead of maintenance and body growth [2]. Gains in feed efficiency will occur mostly from focusing on ways to save on feed inputs through new selection criteria that focus on feed efficiency as part of the breeding policy and nutritional grouping. Nutritional grouping is a herd management practice that provides different diets to different groups of lactating cows to better fulfill their nutrient requirements. Ben Meir et al. added that practices in Israel such as to feed a low roughage (31–37% of dry matter) total mixed ration ad libitum to all lactating cows promoted overeating among inefficient cows and contributed to their feed inefficiency. Therefore, the use of moderate feed restriction was suggested for improving the feed efficiency or selection of inefficient cows. VandeHaar et al. concluded that one way to save feeding costs and improve feed efficiency was to decrease the maintenance requirement by selecting smaller cows [2]. However, the effect of maintenance on efficiency is probably the same whether we achieve more milk with a larger bodyweight or less milk with a smaller body weight. Nevertheless, the best way to improve feed efficiency could be to use a selection index that favours greater milk production and smaller bodyweight jointly.

4.2. Effect of Feed Traits on Behaviour

The coefficient of variation for rumination time (min/d) among animals was previously reported as 16% (12 cows monitored, [32]), and in another study 48% (79 cows monitored [16]). In the current study, the coefficient of variation for rumination time (min/d) was 12.5% (26 cows monitored, Table 1). Dado and Allen found that the cow variability determined by the coefficient of variation was, for eating time (min/d) among cows, about 17%, and for feeding time (min/d) 2 to 3-times higher [32]. In the current study, the coefficient of variation for feeding time (min/d) was 25.3% (26 cows monitored, Table 1). Watt et al. [33] found that the physiological maximum of rumination time was about 600 to 720 min/d, which may occur in cattle fed high-fibre diets and added that most lactating dairy cows fed mixed diets seldom ruminate this long. Our study showed that the most efficient cows with the lowest FCR (≤1.4 kg feed/1 kg milk) had the highest rumination time (597 min/day; $p < 0.05$), feeding time (298 min/day; $p < 0.05$), rumination/activity ratio (4.39; $p < 0.05$), and rumination/feeding ratio (2.04; $p < 0.05$). Less active cows (activity time 164 min/day; $p < 0.05$) were the most efficient cows with the lowest FCR (≤1.4 kg feed/1 kg milk). The differences in the rumination time, feeding time, and activity time between high feeding rate (≥0.26 kg/min) and low feeding rate (≤0.14 kg/min) cows were +39 min/day, +40 min/day, and −31 min/day, respectively (Table 4). Figure 2 includes observations where milk yield was more than 30 kg/day. The most feed efficient cows with the highest milk yield and lowest FCR are shown in the black circle. The rumination time of most feed efficient cows (FCR ≤ 1 kg feed/1 kg and milk yield ≥ 35 kg/day, Figure 2) ranged between 532 and 663 min/day. The optimum rumination time is needed to minimise the risk of rumen acidosis, enhance fibre digestion, and promote high levels of feed intake in dairy cows [13].

Ruminal health is optimised when cows consume smaller meals, slowly and frequently, while minimising feed sorting and as a result efficiency of milk production is improved [34]. Our study showed that groups of cows with lower feed intake (≤39 kg/day, Table 3) tended to have longer feeding time, resting time, and rumination/activity ratio. The group of cows with the lowest feeding rate (≤0.14 kg/min) had the highest resting time (398 min/day; $p < 0.05$), activity time (222 min/day; $p < 0.05$), rumination/activity ratio (2.92; $p < 0.05$), and rumination/feeding ratio (2.06; $p < 0.05$; Table 3). Moraes et al. reported that the expected maximum efficiency is 35 to 40% [27]. This implies that feed efficiency reaches a maximum as cows intake about 5× that required for maintenance. According to the equations used in the NRC [24], efficiency peaks at 4× maintenance intake, where peak production yields approximately 45 kg of milk (3.5% fat) per day for a 680-kg cow. However, where efficiency peaks in practice is not clear. According to VandeHaar et al., high feed intake can lead to digestibility and rumen depression and it may outweigh the dilution of maintenance [2]. The correlation coefficient between rumination time and feed intake was −0.25 (26 monitored cows, $p < 0.001$, Table 1). Based on these findings we can assume that an expected maximum efficiency around 40% may be overly optimistic and feed efficiency may decline with increased intake. Our study showed similar results and can confirm these findings based on Figure 2, where darker points show higher feed intake with increased FCR (feed efficiency).

Ben Meir et al. found complementarity between rumination time and feeding time ($r = -0.34$, $p = 0.03$) [8]. A similar inverse relationship was reported also for cows with decreased eating time due to feed restriction or diet composition; rumination time increased to compensate for the longer particle size of swallowed feed due to feed restriction [13]. White et al. [35] stated that this compensatory effect does not occur if cows are ruminating near their physiological maximum, which is sometimes the case for high-yielding dairy cows. Similar findings were highlighted in our study, with level of rumination/feeding ratio related to the level of milk yield and relative milk yield; the higher was the milk yield, the higher was the rumination/feeding ratio ($p < 0.05$, Table 2). The correlation coefficient between rumination time and feeding time was −0.10 (26 monitored cows, $p < 0.001$; Table 1).

Finally, several nutrition models have been developed to predict feed intake, but even the best models have been unable to account for >70% of the variation of feed intake. Models for feed intake need to be complex and should include the behaviour of cows [7]. In addition, to support prediction of feed intake, several studies have shown that changes in feeding behaviour may indicate that the cow is approaching calving or has become ill [36,37]. We can confirm similar findings, the group of cows with lower feed intake (≤39 kg/day, Table 3) tended to have longer feeding time, resting time, and rumination/activity ratio. Prolonged resting time of cows often indicates the existence of a problem. It is well known that early identification of sick cows could minimise disease duration, improve animal welfare, and decrease economic losses [1].

5. Conclusions

Increased feed intake encouraged milk production, but high-yielding cows differed in their feed utilisation. The most feed inefficient cows had the highest milk yield, feed intake, feeding rate, and body condition score. However, the most efficient group of cows had the highest relative milk yield, which was recalculated as milk yield per 100 kg of body weight. Incorporating feeding behaviour into the dry matter intake model can improve its accuracy in the future and benefit breeding programmes. Towards formulating this model, we identified the relevance of aspects of feeding behavior towards FCR. The highest rumination time, feeding time, and rumination/feeding ratio, were found in the most efficient group of cows, suggesting that rumination activity was very important. Moreover, the group of cows with the highest feed intake expressed one of the lowest rumination times and included the most inefficient cows. We can assume that high feed intake can lead to rumen and digestion problems and negatively affect profitability. Cows with lower activity time were the most feed-efficient. Animal variation in maintenance energy requirements appears to occur. These findings concerning feeding behaviour could be used to achieve improved nutrition management, to increase feed efficiency, and enhance the welfare status of animals. Healthy animals are the first prerequisite for breeding for resilience to environmental changes and for focusing more directly on increasing the amount of milk from each unit of feed or each unit of land.

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