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Whole lactation feeding behaviour of Simmental cows in commercial dairy farms

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A B S T R A C T

Understanding the changes that occur in dairy cows during lactation may be important to better manage the herd and optimise production. Nowadays, thanks to the spread of new technologies in commercial dairy farms, it is possible to obtain numerous individual data throughout its productive career. Using daily data collected with sensors available in commercial farms, we investigate the relation between feeding behaviour, parity, and performance in Italian Simmental dairy cows. The main aim was to better understand how lactation affects cows feeding behaviour. Individual data on milk performance, eating time (ET), rumination time (RT), and body weight (BW) from 80 dairy cows during the whole lactation were collected for 12 months. Animals were divided into two groups considering parity (primiparous, PP, and multiparous, MP) and three feeding behaviour classes from low to high values (eating time classes, ETC; rumination time classes, RTC). Data was statistically analysed with a factorial design with animals as repeated measurements. ETC is positively related to milk composition, as animals in the higher ETC are more productive, especially at the two ends of the lactation curve ($p < 0.01$). An interesting relation between ET and RT was found. Milk production is also positively related to RTC, but surprisingly, no effect was found on milk fat ($p > 0.05$). As expected, a positive relation between parity and milk production was found ($p = 0.002$), but no differences were found in milk composition or somatic cell count between the two parity groups. PP cows have greater eating activity but lower estimated dry matter intake than MP cows (21.85 vs. 23.43 kg/d, $p < 0.001$), which meet their requirements with an increased eating rate (105 vs. 89 g/min, $p = 0.002$) and a tendentially higher RT (525 vs. 506 min/d, $p = 0.015$). All this information can be combined and integrated to provide valuable support to the farmer in managing the herd.

1. Introduction

Feeding behaviour is a hot topic that links behaviour and nutritional sciences. Some recent studies have investigated how feeding behaviour (eating and rumination time) affects the performance, milk quality, health status, and production efficiency of dairy cows (Castaneda et al., 2024; Jurkovich et al., 2024). In fact, different feeding behavioural patterns affect daily nutrient intake and functionality of the rumen, which is the primary driver of nutrient utilisation in ruminants and makes their digestive processes efficient. Abnormal behaviours may be associated with ruminal pH imbalances, which have a severe impact on production and animal health (Antanaitis et al., 2024). The effect of rumination time has been extensively explored, and it is often used as a proxy for changes in the health and welfare of the animal, as well as being potentially linked to some milk quality traits (fat composition; Beauchemin, 2018). Otherwise, eating time is less used as an indicator, despite some research suggesting that chemical and physical properties of diets have some influence on it (Florit et al., 2023) and that it is related to milk production (Johnston and DeVries, 2018).

In recent years, remarkable progress has been made in developing innovative technologies known as "precision livestock farming" on commercial farms (Kaur et al., 2023). The main goals for this development are to direct the intensification of livestock production toward greater productive efficiency and to respond to social requests to improve sustainability and animal welfare. These technologies are aimed at monitoring and sensing the health, physiology, and activity of animals, as well as their feeding behaviour. Milking robots and accelerometers are among the most widely used technologies in modern commercial dairy farms, having become firmly established over the years. These technologies allow collecting several individual data concerning milk production, body weight, and feeding behaviour throughout the entire lactation period and provide useful insights to the

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farmer regarding the presence of nutritional, management, or welfare issues.

It is well known that during lactation a complex evolution of nutritional and physiological conditions occurs in the dairy cow, which has to support milk production, begin and maintain a reproductive cycle, and restore the body reserves. Changes in behaviour could provide relevant information about the nutrition, reproduction, health, and overall well-being of dairy cows (Benaissa et al., 2019). In particular, having continuous data on feeding behaviour allows us to link it to production aspects and obtain useful indicators for better herd management in every single lactation phase. The scientific literature contains limited information about the modification of feeding behaviour of cows measured by accelerometers on commercial farms and on the changes that occur during lactation. In addition, most nutritional research in the dairy industry is conducted on the most specialised and widely distributed dairy breeds in the world (Holstein Friesian), while there is a scarcity of experimental data on dual-purpose breeds. These breeds are gaining popularity due to their potential to support sustainable livestock systems based on a balanced production of meat and milk. The objective of this study was to investigate how feeding behaviour changes during the lactation phases and in relation to the parity and production performance of Simmental cows.

2. Materials and methods

The study used sensors and datasets already in use on the commercial farms visited. Some non-invasive observations of the dairy cows were carried out in a way that minimised disturbance. Therefore, ethical approval by an institutional animal welfare committee was not required.

2.1. Data collection

Five commercial dairy farms in the northeast of Italy (Friuli Venezia Giulia region) with a total of 350 Italian Simmental dairy cows were considered for this study. Within these animals, we considered cows that had complete data for the whole lactation (n = 80; in particular n = 21; 17; 17; 13; 12 for farm), which were monitored for 12 months (between November 2022 and October 2023). To select farms, the following inclusion criteria were used: all the dairy cows were housed in a cubicle system and milked using an automatic milking system (AMS) with free and voluntary access to milking; all the AMS had a scale to measure the body weight (BW) at every milking event; all the cows were equipped with a specific sensor capable of detecting feeding behaviour (SenseHub Dairy, Allflex Livestock Intelligence, Merck & Co., Rahway, USA). Specifically, the sensor was a 3D accelerometer that allowed continuous monitoring of acceleration along orthogonal X, Y, and Z axes. It was secured to the left side of the animal's neck using a strap, and a weight attached to the lower end of the strap helped keep the sensor in the right place. An accurate description of eating and rumination behaviour was reported in Ferrari et al. (2025). To identify these activities, software (provided by the manufacturer) processes data analysing animal head position. Specifically, when cattle are eating, their head is positioned above the feed bunk, while during rumination, the head remains upright whether the animal is lying down or standing. The raw data of feeding behaviour were continuously recorded and stored in 2-hour blocks for 24 h, then uploaded to a processing unit and elaborated to return the daily feeding behaviour data (min/d). This sensor was validated by Merenda et al. (2020), finding very high correlations between visual observations and time recorded at 30-minute intervals (rumination, $R^2 = 0.97$; eating, $R^2 = 0.91$).

The management of partial mixed rations (PMR) and compound feed was similar within farms and over the year in terms of ingredients and chemical composition. The farms were visited monthly, during which PMR and compound feed samples were collected. The particle size was assessed by fractionating a fresh sample of PMR with the Penn State Particle Separator (mesh diameters: 19, 8.8, and 1.18 mm) as reported by Kononoff et al. (2003). The dry PMR (obtained in an oven at 60°C for 48 h) and compound feeds were assayed in duplicate for DM, crude protein (CP; N x 6.25) (AOAC, 2016; methods 930.15, 976.05, and 942.05, respectively) and for the neutral detergent fibre (NDF) content, measured by an Ankom II fibre analyzer (Ankom Technology Corporation, Fairport, NY) following the procedure of Van Soest et al. (1991) without correction for residual ash and by applying a pre-treatment of samples with α-amylase. The PMR, provided *ad libitum,* was primarily based on fibrous ingredients (such as whole plant corn or sorghum silage and alfalfa hay) and compound feed consisting mainly of cereal flours, corn and barley, and soybean meal (DM = 55.8 ± 2.2 %, NDF = 47.4 ± 4.4 % DM, CP = 13.4 ± 0.7 % DM; particle size = 7.78 ± 1.56 mm). The pellet compound feed offered in the AMS during milking has a similar chemical composition within the farms (DM = 88.8 ± 0.8 %, NDF = 24.6 ± 2.3 % DM, CP = 20.0 ± 1.5 % DM), and the quantity administered individually to cows was based on expected individual milk yield.

During the monthly visits, individual data were also collected. Data including performance data (days in milk (DIM), lactation number, milk yield (MY), milk composition (fat, protein, and lactose), and somatic cell count (SCC), as well as feeding behaviour such as eating time (ET) and rumination time (RT), and BW were extracted from the AMS computer (Horizon management software, Lely Industries, Maassluis, the Netherlands) for the 30 days preceding each visit. On the day of the visit, all cows were assessed for body condition score (BCS) by a trained expert using the method described by Edmonson et al. (1989), with a 5-point scale and scores recorded in increments of 0.25 points.

2.2. Data calculations

Fat- and protein-corrected milk (FPCM) was calculated using the following equation (Kok et al., 2016):

$$FPCM(kg/d) = milk\ yield(kg/d) \times [0.337 + 0.116 \times fat\ content(\%) + 0.06 \times protein\ content(\%)]$$

Estimated dry matter intake (eDMI) was calculated using the equation derived from the NRC, (2021) (equation 2–1) (see Supplementary Material):

$$eDMI(kg/d) = [3.7 + (Parity \times 5.7) + 0.305 \times MilkE(Mcal/d) + 0.022 \times BW(kg) + (-0.689 - 1.87 \times Parity) \times BCS] \times [1 - (0.212 + Parity \times 0.136) \times e\hat{}(-0.053 \times DIM)]$$

where parity is a factor ranging from 0 (primiparous cows) to 1 (multiparous cows), BCS ranging from 1 to 5 points, and the daily energy milk yield (MilkE, Mcal/d) was calculated using the equation 3–14a from NRC, (2021) modified to obtain daily data:

$$MilkE(Mcal/d) = (9.29 \times kg\ fat/kg\ milk + 5.5 \times kg\ crude\ protein/kg\ milk + 3.95 \times kg\ lactose/kg\ milk) \times milk\ yield(kg/d)$$

The eating rate (ER, g DM/min) was calculated by dividing eDMI by ET.

To determine individual changes in BW, weekly means of BW were computed using daily measures for each animal. Daily change in BW (ΔBW) was calculated by the difference between the last and the first measure of a week, divided by the number of days between measurements. Then ΔBW has been reported as a percentage of BW.

We calculated the energy requirements for lactation (NELt) following the NRC, (2021) equations, considering net energy for lactation (NEL) as a basic unit. In particular, NEL maintenance requirements were calculated using Equation 3–13 as follows:

$$NELmaint(Mcal/d) = 0.10 \times BW(kg)^{0.75}$$

The NEL concentration in milk is equivalent to the sum of the heats of combustion of individual milk components and was calculated using the same equation previously described, modified to obtain daily data (MilkE; Equation 3–14a). The sum of NELmaint and MilkE is the total daily energy requirements of cows.

2.3. Statistical analysis

All the statistical analyses were conducted using SAS 9.4 (SAS Institute, 2019; SAS Institute Inc., Cary, NC, USA). The normality of data distribution was checked using the UNIVARIATE procedure. Outlier removal for feeding behaviour traits was performed as described in detail in Florit et al. (2023).

Each lactation phase ($n = 10$) was defined every 30 DIM starting from the calving day (DIM = 0).

To analyse the association between parity group and phase of lactation, animals were divided into two groups, primiparous (PP; $n = 25$) and multiparous (MP; $n = 55$).

For the analysis of the association between feeding behaviour and phase of lactation, cows were distributed in three classes of ET length (ETC) and RT length (RTC) according to Codl et al. (2023). Daily data, including ET and RT, were divided based on their arithmetic mean and standard deviation: Low class (L-ETC and L-RTC) included values lower than $\bar{x}$ - 1/2 SD; Medium class included values between $\bar{x}$ - 1/2 SD and $\bar{x}$ + 1/2 SD (M-ETC and M-RTC); High class included values higher than $\bar{x}$ + 1/2 SD (H-ETC and H-RTC).

The data about feeding behaviour (ET and RT), feed intake, energy requirements, milk performance and animal characteristics were analysed according to a factorial design using the MIXED procedure, considering animal as repeated measurement. The following model was used:

$$Y_{ijkl} = \mu + \alpha_i + (\beta_j)_i + \gamma_k + \delta_l + \gamma\delta_{kl} + \varepsilon_{ijkl}$$

where $Y_{ijkl,}$ is the experimental data, μ is the overall mean, α_i is the random effect of the farm (block, i = 1,5), β_j is the random effect of cows (j = 1,80) within the i^{th} farm, γ_k is the effect of lactation phases (k = 1,10), δ_l is the fixed effect of parity (l=1,2), and ε_{ijkl} is the random error. The LSMEANS were adjusted with the Tukey-Kramer for multiple comparisons.

The analysis of the association between ETC and RTC and the phase of lactation was performed with the above-described model where the parity factor was substituted with the fixed effect of ETC (l=1,3) and RTC (l=1,3). The statistical significance was declared at $p < 0.01$ and $p < 0.05$.

3. Results

Table 1 and Table 2 show the effect of parity and lactation phase on milk performance, BW, eDMI, and feeding behaviour (ET, RT, and ER) of dairy cows. Within both parity classes, MY increased significantly from the first to the subsequent lactation phase and then was stable till 121–150 (or 61–90 in MP) DIM before declining, reaching a low point after 241 DIM. A similar trend was found with FPCM. The MY of PP was lower ($p < 0.001$) than MP over the first six months of lactation. Lactation phase significantly affected milk composition, SCC, and BW variations ($p < 0.001$). Milk traits (fat, protein, fat:protein ratio, and SCC) showed a usual pattern, with a decrease from the first to the subsequent lactation phases, followed by low values and a regrowth at the conclusion of lactation. BW increased during lactation, and there was a significant difference due to parity (681 vs 761 kg for PP and MP, respectively; $p < 0.001$). During the beginning of lactation, there was an intense mobilisation of BW, while thereafter BW incremented.

For both parity classes, the lowest ET was detected at the start of lactation, followed by an increase and rather consistent values (from 61 to 210 for PP and 31–210 for MP), with a tendency to drop in the latter lactation stages, where the PP cows showed values higher than MP (between 211 and 270 DIM). RT had the lowest value during the first 30 DIM and then remained consistent until 91–120 DIM and grew somewhat in subsequent lactation phases. PP cows had a slightly shorter RT than MP cows (506 vs 525 min, $p = 0.015$). Within both parity classes, eDMI increased from the first to the second lactation phase, then stabilised in PP cows but declined in MP cows. In addition, the NEL needs increased from the first to the subsequent lactation periods, remained steady from 31 to 150 DIM, and subsequently decreased. Compared to MP cows, PP cows consumed less DM ($p < 0.001$) and had lower NEL needs ($p = 0.002$) for the first six months of lactation.

In the subsequent presentation of results, we focused only on the main effects of ETC and RTC (Fig. 1 and Fig. 2). MY increased significantly ($p < 0.001$) accordingly with ETC (Fig. 1), both at the start (0–30 DIM) and at the end of lactation (241–305 DIM). Cows who ate more time during the day also ruminated more (504, 519, and 530 RT, $p < 0.001$ for L-ETC, M-ETC, and H-ETC, respectively; Fig. 1). Cows in the L-ETC exhibited the highest ER value compared to medium and high ETC throughout the lactation cycle (Fig. 1). For eDMI and NEL requirements, the sole statistical difference across ETC occurred in the final phase of lactation, whereas both variables increased from the first to second lactation phase, peaked between 60 and 120 DIM, and subsequently fell (Table 3; see Supplementary Material).

MY and FPCM increased significantly ($p = 0.028$, Fig. 2) with RTC only in the second lactation phase (31–60 DIM). Cows who ruminated more time throughout the day had longer ET (260 and 255 vs 244 min, $p < 0.001$ for H-RTC and M-RTC vs. L-RTC; Fig. 2). Cows in the L-RTC had the greatest ER value compared to M-RTC and H-RTC throughout the lactation cycle ($p = 0.001$, Table 4; see Supplementary Material). Within each RTC, eDMI increased from the first to the second lactation phase, then declined. Only at lactation phases corresponding to 31–90 DIM, the M-RTC and H-RTC had higher eDMI than L-RTC cows (Table 4; see Supplementary Material).

4. Discussion

The diffusion at farm level of sensors useful for measuring individual daily data has significantly increased the study of mechanisms related to feeding behaviour in dairy cows (Benaissa et al., 2019; Castillo-Lopez et al., 2023; Poulopoulou et al., 2019). However, many studies on feeding behaviour mainly focus on the most critical stages of lactation (transition period or early lactation), where these traits can be a useful indicator of health and wellness status, as reported in a recent meta-analysis (Sadiq et al., 2024). In our survey, the differences between different phases in the whole lactation were considered to obtain some interesting insights regarding the effect of feeding behaviour and production data. The study is mainly addressed to identify opportunities for improving the general welfare and nutrition efficiency of productive animals that are relevant issues.

4.1. Feeding behaviour and performance traits

Voluntary feed intake of dairy cows is regulated by several factors, including the stage of lactation, the size of the animal (which in turn depends on breed and age), the social interactions (hierarchy and competition), and the management and composition of the ration (in terms of number of distributions, particle length, and fibre content) (Grant and Albright, 2000). Within these mechanisms, the feeding behaviour plays a role, but the knowledge regarding this topic is still conflicting (Azizi et al., 2009; De Mol et al., 2016; Pahl et al., 2016). Finding the links between this aspect and dairy production is critical to supporting proposals for ways that enhance milk yield and animal welfare.

As can be clearly seen from Fig. 1, there is a group of cows (i.e., the L-ETC group), which can be defined as “quick eaters”, having short eating times, very high ER, and exhibiting low milk yields and rumination

Table 1
The effect of parity and lactation phases on milk performance, BW and BW changes.

Item	Parity	DIM (d)										Avg.	RMSE	p - value		
		0–30	**31–60**	**61–90**	**91–120**	**121–150**	**151–180**	**181–210**	**211–240**	**241–270**	**271–305**			Parity	DIM	Parity*DIM
MY (kg/d)	PP	22.87^{CY}	29.18^{AY}	29.32^{AY}	28.28^{ABY}	27.19^{ABY}	25.79^{BCY}	25.38^{BC}	24.19^{BC}	21.61^{CD}	17.43^{D}	25.12	3.711	0.002	< 0.001	< 0.001
	MP	32.67^{CX}	38.05^{AX}	36.29^{ABX}	33.98^{BCX}	32.09^{CX}	29.82^{DX}	27.40^{D}	24.45^{E}	20.67^{F}	18.27^{F}	29.37				
	Avg.	27.77	33.62	32.80	31.13	29.64	27.80	26.39	24.32	21.14	17.85	-				
FPCM (kg/d)	PP	22.94^{BY}	27.92^{AY}	28.55^{AY}	28.14^{AY}	27.60^{AY}	26.69^{AB}	26.52^{AB}	25.22^{AB}	22.79^{BC}	18.83^{C}	25.52	4.068	0.002	< 0.001	< 0.001
	MP	32.19^{BX}	35.92^{AX}	34.90^{ABX}	33.58^{ABX}	32.29^{BX}	30.36^{BC}	28.36^{CD}	25.57^{D}	21.82^{E}	19.49^{E}	29.45				
	Avg.	27.56	31.92	31.72	30.86	29.94	28.52	27.44	25.39	22.30	19.16	-				
Milk fat (%)	PP	4.24	3.62	3.70	3.86	4.04	4.23	4.29	4.26	4.36	4.64	4.12	0.331	0.854	< 0.001	0.544
	MP	4.13	3.67	3.74	3.88	3.99	4.07	4.21	4.31	4.40	4.60	4.10				
	Avg.	4.19^{BCD}	3.65^{G}	3.72^{FG}	3.87^{EF}	4.01^{DE}	4.15^{CD}	4.25^{BC}	4.28^{BC}	4.38^{B}	4.62^{A}	-				
Milk protein (%)	PP	3.94	3.48	3.50	3.54	3.58	3.59	3.60	3.62	3.64	3.58	3.61	0.176	0.279	< 0.001	0.532
	MP	3.82	3.48	3.48	3.48	3.51	3.54	3.56	3.58	3.65	3.61	3.57				
	Avg.	3.88^{A}	3.48^{D}	3.49^{CD}	3.51^{CD}	3.54^{BCD}	3.57^{BCD}	3.58^{BCD}	3.60^{BC}	3.65^{B}	3.60^{BC}	-				
SCC ($\times 10^3$/mL)	PP	225	64	63	82	87	151	134	85	109	186	119	189.0	0.144	< 0.001	0.206
	MP	218	125	99	142	159	126	119	182	255	208	163				
	Avg.	221^{A}	95^{B}	81^{B}	112^{AB}	123^{AB}	139^{AB}	126^{AB}	134^{AB}	182^{AB}	197^{AB}	-				
Fat: Protein	PP	1.08	1.05	1.06	1.09	1.13	1.18	1.20	1.18	1.21	1.30	1.15	0.103	0.921	< 0.001	0.817
	MP	1.10	1.06	1.07	1.12	1.14	1.15	1.18	1.21	1.22	1.29	1.15				
	Avg.	1.09^{EF}	1.05^{F}	1.07^{F}	1.11^{DEF}	1.14^{CDE}	1.17^{BCD}	1.19^{BC}	1.20^{BC}	1.22^{B}	1.29^{A}	-				
BW (kg)	PP	660	649	661	671	674	677	688	698	712	721	681^{Y}	31.7	< 0.001	< 0.001	0.889
	MP	739	727	751	756	759	759	765	774	785	793	761^{X}				
	Avg.	700^{DE}	688^{E}	706^{DE}	714^{CD}	716^{BCD}	718^{BCD}	727^{BC}	736^{AB}	749^{A}	757^{A}	-				
ΔBW (%BW)	PP	−0.18	0.02	0.04	0.04	−0.01	0.03	0.04	0.02	0.06	0.00	0.01	0.204	0.864	< 0.001	0.693
	MP	−0.13	0.00	0.07	0.02	−0.05	0.04	0.03	0.05	−0.02	0.05	0.01				
	Avg.	-0.16^{B}	0.01^{A}	0.05^{A}	0.03^{A}	-0.02^{A}	0.03^{A}	0.03^{A}	0.04^{A}	0.02^{A}	0.02^{A}	-				

Parity: PP = primiparous; MP = multiparous; DIM = days in milk; RMSE = residual mean square error; MY = milk yield; FPCM = fat- protein corrected milk; SCC = somatic cell count; BW = body weight; ΔBW = daily BW variation in percentage of animal BW.
Within each lactation phase different letters show statistical differences between parity groups at a $p < 0.01$ (X, Y) and at a $p < 0.05$ (x, y).
Within each parity group different letters show statistical differences between lactation phases at a $p < 0.01$ (A, G) and at a $p < 0.05$ (a, g).

Table 2
The effect of parity and lactation phases on feeding behaviour parameters, feed intake, and dietary energy requirements.

Item	Parity	DIM (d)										Avg.	RMSE	p -value		
		0–30	31–60	61–90	91–120	121–150	151–180	181–210	211–240	241–270	271–305			Parity	DIM	Parity*DIM
ET (min/d)	PP	192^{D}	240^{C}	271^{A}	283^{AB}	291^{A}	279^{A}	284^{A}	280^{ABX}	271^{AX}	254^{BC}	264	29.8	0.088	< 0.001	< 0.001
	MP	220^{C}	250^{AB}	255^{A}	261^{A}	266^{A}	259^{A}	257^{A}	246^{AY}	236^{BCY}	236^{BC}	249				
	Avg.	206	245	263	272	278	269	271	263	254	245	-				
RT (min/d)	PP	471	491	502	500	509	514	524	524	517	508	506^{y}	30.9	0.015	< 0.001	0.074
	MP	510	526	517	514	516	530	538	539	530	526	525^{x}				
	Avg.	491^{C}	508^{BC}	509^{BC}	507^{BC}	512^{AB}	522^{AB}	531^{A}	532^{A}	524^{AB}	517^{AB}	-				
ER (g DM/min)	PP	111^{A}	97^{ABCD}	86^{BCDY}	84^{BCDY}	82^{DY}	86^{BCDY}	82^{CDY}	82^{CDY}	85^{BCDY}	91^{BCD}	89	16.3	0.002	< 0.001	< 0.001
	MP	105	106	108^{X}	106^{X}	102^{X}	103^{X}	103^{X}	105^{X}	109^{X}	102	105				
	Avg.	108	102	97	95	92	95	93	93	97	97	-				
eDMI (kg/d)	PP	18.90^{BY}	21.50^{AY}	22.25^{AY}	22.52^{AY}	22.45^{AY}	22.27^{AY}	22.54^{A}	22.44^{A}	22.17^{A}	21.49^{A}	21.85	1.150	< 0.001	< 0.001	< 0.001
	MP	20.55^{FX}	24.28^{BX}	25.20^{AX}	24.65^{ABX}	24.38^{ABCX}	23.87^{BCDX}	23.64^{C}	23.03^{DE}	22.54^{E}	22.12^{E}	23.43				
	Avg.	19.72	22.89	23.73	23.59	23.42	23.07	23.09	22.73	22.36	21.80	-				
NELt (Mcal/d)	PP	30.98^{BY}	33.95^{AY}	34.31^{AY}	34.05^{AY}	33.70^{AY}	33.94^{AB}	32.96^{AB}	31.90^{AB}	30.16^{BC}	27.26^{C}	32.22	2.852	0.002	< 0.001	< 0.001
	MP	38.22^{ABCX}	40.40^{AX}	39.32^{ABX}	37.92^{BX}	36.98^{CDX}	35.59^{DE}	34.05^{EF}	31.95^{F}	29.12^{G}	27.65^{G}	35.12				
	Avg.	34.60	37.17	36.81	35.99	35.34	34.27	33.50	31.93	29.64	27.45	-				

Parity: PP = primiparous; MP = multiparous; DIM = days in milk; RMSE=residual mean square error; ET = eating time; RT = rumination time; ER = eating rate; eDMI = estimated dry matter intake; NELt = total daily net energy requirements (maintenance and lactation).
Within each lactation phase different letters show statistical differences between parity groups at a $p < 0.01$ (X, Y) and at a $p < 0.05$ (x, y).
Within each parity group different letters show statistical differences between lactation phases at a $p < 0.01$ (A, G) and at a $p < 0.05$ (a, g).

activities. It is possible that this is a consequence of physiological and compartmental conditions, but it is also plausible that these cows exhibit such behaviour as a result of stressed and/or fearful conditions (e.g., density of animals and not suitable feeding area or not comfortable conditions). Further research is required to confirm and elucidate the use of these specific feeding behaviours (e.g., ET ranking) in identifying cows at risk of poor welfare and at low efficient production conditions. Management solutions are needed to reduce this fraction of cows to improve herd nutrition and animal welfare at minimum.

The relationship founded between ETC and milk performance throughout lactation (Fig. 1) supports the previous findings of Johnston and DeVries (2018), where milk production increased for about 1.74 kg/d for every increased hour of time spent eating, and Jaeger et al. (2019), where daily feeding activity increases from 15 % to 25 % from low MY class (< 15 kg) to high MY class (> 30 kg). Moreover, an interesting positive association is found between ETC and RT (Fig. 1). Previous results were conflicting, as some authors found a weak ($r = -0.14$, Jaeger et al., 2019), negative ($r = -0.64$, Dado and Allen, 1994), or positive ($r = +0.27$, White et al., 2017) correlation between ET and RT.

The RT is currently considered an important parameter for defining the health and welfare of cattle, as well as for assessing the management of the farm (Castaneda et al., 2024). Chemical composition (fibre) and physical characteristics (long particle size) of the ration are important drivers of different rumination patterns (Beauchemin, 2018). The association between RT and milk production has been studied extensively (Soriani et al., 2013; Souza et al., 2022), and as we expected, the positive association between RTC and MY was found (Fig. 2). Considering that a normal rumination activity contributes to a favourable rumen pH, digestion of fibre, and regulation of biohydrogenation processes (Souza et al., 2022), an effect on milk composition, especially fat content, was expected but not found. This is in line with the assumptions of recent studies, which underline how an increase in rumination activity is weakly linked to an increase in milk fat (Andreen et al., 2020; Souza et al., 2022).

4.2. *Parity and performance traits*

The milk yield of dairy cows in this survey is estimated to be 75–90 t for the whole lactation, which is comparable to the average Italian Simmental milk yield and 25 % lower than the most widespread specialised breed in Italy (Holstein Friesian) (AIA, 2023). However, our study shows that Simmental cows perform better in terms of fat and protein content in milk (4.11 % and 3.59 %, respectively) than Holstein Friesian (3.85 % fat and 3.35 % protein; AIA, 2023). Despite these differences in milk yield, the trend of milk production and the other related traits (such as BW, SCC, and milk components) follow the typical shape found in specialised breeds. The eDMI was estimated using daily collected individual data (see Supplementary Material) and is consistent with the known research on Simmental cows (Stauder et al., 2020). The initial increase of feed intake (during the first 90 DIM) is related to the growth of milk production, which leads the animal to be in a phase of negative energy balance due to a consistent growth of nutritional needs (Dahl, 2020). This explains our findings where high milk production and energy requirements are associated with a decrease of BW (especially in the first times after calving) (Fig. 3; see Supplementary Material).

The available literature is rich of studies regarding the positive relationship between parity and increased milk production (Brown et al., 2022; Munksgaard et al., 2020). MP cows tend to have better performance and improved physiological adaptations to lactation requirements compared to PP cows, as also indicated by our results (Table 1). As expected, there is an effect of the lactation phase on SCC, as it is known that the number of cells gradually increases, especially in the last times before the dry-off period (Sharma et al., 2011), and the higher values in the first phase of lactation might be the result of the mammary structure's requirement to rebuild its productive functionality following

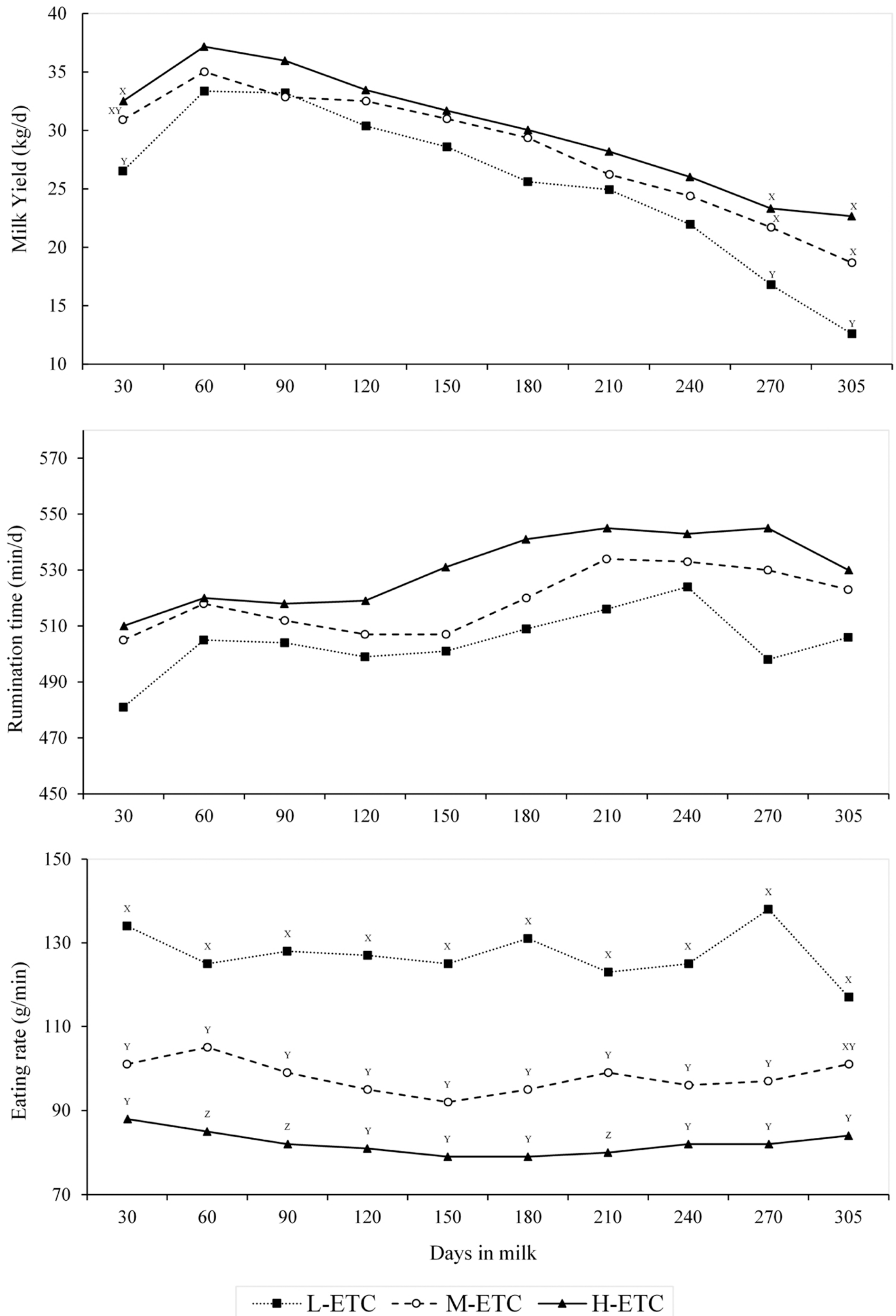

Fig. 1. Milk yield, rumination time and eating rate of cows in different eating time classes (ETC: L-ETC = animals with values of eating time < $\bar{x}$ - ½ SD; M-ETC = animals with values of eating time between $\bar{x}$ - ½ SD to $\bar{x}$ + ½ SD; H-ETC = animals with values of eating time > $\bar{x}$ + ½ SD) during the whole-lactation. ETC bearing different capital letters differ at $p < 0.01$ and lowercase letters differ at $p < 0.05$.

the dry period, which causes a notable loss of epithelial cells in a small amount of milk (Schalm et al., 1971). On the other hand, an effect of parity on SCC is also expected. Previous studies support the knowledge that parity is one of the main risk factors for mastitis, as with age the physiological and anatomical defense mechanisms can deteriorate (Jamali et al., 2018). In this study, MP cows have numerically higher values of SCC but do not reach significance given the known variability of this trait (Table 1).

4.3. *Feeding behaviour and parity*

Despite the lower milk production and nutritional requirements of PP cows, they numerically ate longer but less quantity than the MP cows (Table 2), in agreement with the findings of Azizi et al. (2009), Codl et al. (2020), and Stauder et al. (2020). This may be related to their reduced intake capacity (in terms of digestive volume), or, as supposed by Jaeger et al. (2019), MP cows have adapted their behavioural pattern with experience and managed to eat more by reducing their total ET (4.5 % less per day). Feeding behaviour of primiparous could be due, in

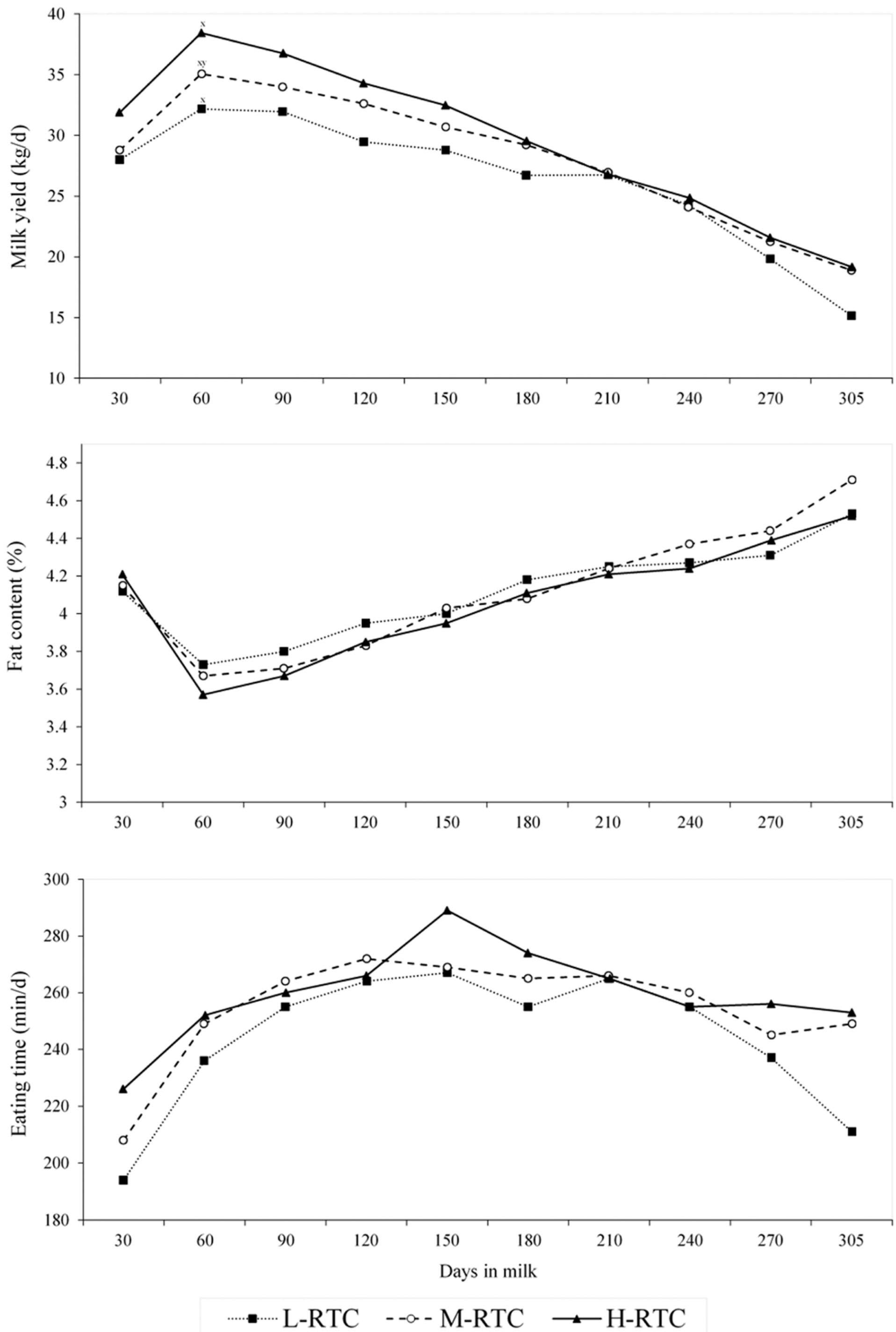

Fig. 2. Milk yield, fat content in milk and eating time of cows in different rumination time classes (RTC: L-RTC = animals with values of rumination time < x̄ - ½ SD; M-RTC = animals with values of rumination time between x̄ - ½ SD to x̄ + ½ SD; H-RTC = animals with values of rumination time > x̄ + ½ SD) during the whole-lactation. RTC bearing different capital letters differ at $p < 0.01$ and lowercase letters differ at $p < 0.05$.

addition to body development and physiological reasons, to a behavioural response (neophobia) to novel lactating diets, which are generally different from those fed before calving. As shown by Mainardes and DeVries (2016), the acceptance of novel feed might increase with the length of exposure, and these authors stated, "There is evidence to suggest that dairy cattle acquire their knowledge from individual trial and errors and from other members of their social group, where feeding behaviour might be influenced by older animals." Another possible explanation is related to the social organisation of the herd. Typically, in commercial farms, cows are raised in mixed groups (PP and MP in the same barn), and the effect of hierarchy may lead PP cows to eat for a shorter time because they have to compete with older, bigger, and more dominant cows. Probably, in our study, the *ad libitum* feed management and the free milking with AMS mitigate this effect, resulting in behavioural patterns similar to those seen in PP and MP cows raised apart (Grant and Albright, 2001).

The significantly higher ER (in 7 lactation stages) (Table 2) in MP cows could be explained by the fact that older cows have a greater feed prehension thanks to their larger size (therefore size of the mouth), which leads to a higher feed intake in less time (Azizi et al., 2009; Brown et al., 2022; Reyes et al., 2024). ER is established to be moderately to strongly related to feed efficiency in beef cattle (Montanholi et al., 2010; Romanzin et al., 2022) and dairy cattle (Brown et al., 2022; Green et al., 2013), as animals with low ER have longer chewing activity and slower intake, with a consequential better mastication, rumen fermentation, and nutrient digestibility (Aikman et al., 2008). While the tendentially higher RT (Table 2) is needed to process a larger bolus (Adenuga et al., 1991; Dado and Allen, 1994) and is related to a better utilisation of feed by ruminal microbiota, maintaining the rumen homeostasis and favouring the passage of feed through the gastrointestinal tract (Kaufman et al., 2018).

4.4. Study limitations

This is an on-farm study that balances the advantage of relying on accurate productive data with the limitation of collecting experimental data using farms' existing monitor systems. A first constraint is predicting individual dry matter intake rather than directly measuring it, because tracking individual consumption is unfeasible on large commercial dairy farms. We used a recent equation provided by NASEM 2021 that is based on individual animal traits and performance (de Souza et al., 2019) to highlight the variations due to animal factors (e.g., stage of lactation, milk yield, body weight). The selected equation accurately predicts DMI for Holstein lactating cows as well as Jersey and Holstein crossbred cows. Simmental cows can be considered quite close to the productive and conformation traits of Holstein crossbred (e.g., milk energy yield and live weight), and to our knowledge, this is the first application of the equation in this breed.

Another potential issue could concern the accuracy and precision standards of the equipment used to collect data on feeding behaviour. To our knowledge, only the validation of an older version of the sensor is available in the scientific literature (Merenda et al., 2020). However, several authors recently have used this instrument to assess the feeding behaviour of dairy cows (Ferrari et al., 2025; Lemal et al., 2024). Furthermore, this equipment is widely used worldwide in dairy herd management. In the present study we were able to demonstrate statistical differences between times and groups of cows, indicating a sufficiently low measurement error.

5. Conclusions

In this study, relationships were found between feeding behaviour and the performance level of animals. In addition, a positive relationship between the two main feeding behaviours measured, ET and RT, is to be underlined and deserves further investigation. These results can lead to the conclusion that, thanks to the help of the different technologies present in commercial farms, it is possible to collect individual data useful for studying and describing different aspects of the lactation curve and the factors involved in its progress. This, combined with other knowledge, can assist the farmers in managing problems within the herd, also with particular attention to the individual animal, from the perspective of precision livestock farming.

CRediT authorship contribution statement

Braidot Matteo: Formal analysis, Data curation. **Romanzin Alberto:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization. **Florit Eleonora:** Writing – original draft, Investigation, Formal analysis, Data curation, Conceptualization. **Spanghero Mauro:** Writing – review & editing, Supervision, Resources, Project administration.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.applanim.2025.106657.

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