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Research article

Contrasting feeding management in the first 21 days *postpartum* in Holstein dairy cows: direct and residual milk responses

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A B S T R A C T

The transition period and its management affect how dairy cows face physiological challenges. Total mixed rations (**TMR**) have been shown as a strategy to address pasture-based system limitations and improve milk production, without consistent information about their use in short periods and residual responses. The study aimed to evaluate contrasting feeding management in the first 21 days *postpartum* on direct and residual milk production responses until 60 days in milk (**DIM**). Sixty-seven mixed parity Holstein dairy cows were used in a completely randomised block design in two treatments across two trials: MD-MD, cows fed a mixed diet (**MD**) with grazing and supplementation with mixed ration, from calving until 60 DIM, TMR-MD: confined cows with TMR provided *ad libitum* during the first 21 DIM in a compost-bedded pack barn and changed to MD at 22 until 60 DIM. During the first 21 DIM (direct response), cows fed TMR produced 11.7% more milk than those on MD-MD. Multiparous (**M**) TMR-MD obtained 18.6% higher milk yield than M MD-MD cows, but no significant differences were detected between primiparous (**P**) cows. After the switch at 22 DIM (residual response), no significant differences were detected between treatments in milk yield. However, the interaction between treatment and parity indicates that M TMR-MD cows exhibited 3.6% more milk than those in MD-MD, as a carryover effect. In contrast, P cows did not differ between treatments. In the first 21 DIM, TMR-MD cows achieved a higher fat concentration and protein yield than MD-MD. Fat yield tended to increase in TMR-MD compared to MD-MD, without treatment effect for lactose yield. In the residual period, TMR-MD cows had higher protein concentrations and tended towards higher fat concentrations than MD-MD cows. The interaction between treatments and parity showed that P TMR-MD cows had higher protein and exhibited a trend towards higher fat concentration than P MD-MD cows. The differential feeding management during the first 21 DIM did not generate differences in body condition score (**BCS**), between treatments or parities. In the residual period, TMR-MD cows achieved a higher BCS than MD-MD cows without differences between parities. No differences were found between treatments in grazing and ruminating time, reflecting a successful adaptation of TMR-MD cows. In conclusion, feeding TMR during the first 21 DIM is an effective strategy for increasing milk yield and achieving short-term carryover effects in M, but not in P cows.

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Implications

The transition period and its management impact dairy cows' physiological challenges. Total mixed rations can address pasture-based diet limitations and improve milk production. However, the impact of short-term total mixed rations on the overall performance of grazing systems remains unclear. Feeding a total mixed ration to multiparous cows during the first 21 days in milk, followed by a switch to a pasture-based diet, led to increased milk yield and positive carryover effects through the first 60 days of lactation. The switch did not lead to losses in body condition score,

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with successful grazing adaptation. This nutritional intervention does not improve productive performance in primiparous cows.

Specifications table

Subject	Nutrition
Type of data	Table, Figure.
How data were acquired	Milk yield was recorded individually by the milk measurement system GEA Dairy Plan C21 (Version 5.3). Milk samples for fat, total protein, and lactose were determined by infrared (MilkoScan FossElectric FT2®, Drachten, The Netherlands). Grazing and rumination time were measured with Boumatic® devices. Sward height was measured with the Sward Stick. Acid and neutral detergent fibres were analysed using an Ankom 200 Fiber Analyzer (Ankom Technology Corp.). Statistical analyses were performed in SAS 9.4 (SAS Institute Inc., Cary, NC, USA).
Data format	Processed, pretreated, and calculated data in Microsoft Excel and SAS.
Parameters for data collection	Data were collected under experimental conditions. Variables: milk production, lactose, protein, fat concentrations and yield, grazing and ruminating time, and body condition score.
Description of data collection	The experimental period was from 21 days precalving to 60 days in milk for both experiments. Before calving, cows were blocked according to lactation number, expected calving date, BW, body condition score, and randomly assigned to the treatment groups. Daily milk production recording, feed sample collections per week, weekly herbage mass, height and allowance recording, milk samples collection per 14 days (experiment 1) and 7 days (experiment 2), daily grazing and rumination recording, and body condition score every 15 days by the same person.
Data source location	Institution: Estación experimental Mario A. Cassinoni, Facultad de Agronomía, Universidad de la República. City: Paysandú Country: Uruguay Latitude: 32°23′8.58″S Longitude: 58° 3′18.87″W
Data accessibility	Repository name: https://zenodo.org/ Data identification number: https://doi.org/10.5281/zenodo.14030724
Related research article	None

Introduction

The transition period in dairy cows is arbitrarily defined as the 21 days before and after calving (Grummer et al., 1995) and is one of the most critical stages. It is characterised by the mobilisation of body reserves and a decline in dry matter intake (**DMI**), leading to negative energy balance and losses in body condition score (**BCS**) (Grant and Albright, 1995). In pasture-based systems, dairy cows face limitations in achieving high DMI and fully expressing their potential milk yield compared to cows fed a total mixed ration (**TMR**) (Kolver and Muller, 1998). In addition, grazing systems often struggle to consistently provide sufficient nourishment in quantity and quality throughout the year, resulting in a structural imbalance between pasture supply and animal demand (Chilibroste et al., 2011; Kay et al., 2015). This imbalance is particularly pronounced during early lactation, threatening productive performance and system profitability. Implementing optimal feeding strategies is essential for reducing the gap between nutrient requirements and intake, and for achieving desired milk yields while minimising the magnitude and duration of negative energy balance (Meikle et al., 2018) in early lactation.

To address the limitations of grazing systems while improving milk production, the use of mixed diets (**MD**), which combine grazing with the supplementation of a mixed ration (a balanced feed comprising silage and concentrate to complement the nutrients obtained from grazing), as well as TMR, has been proposed (Fajardo et al., 2015; Méndez et al., 2023). Feeding TMR increases milk yield by 38% (O'Neill et al., 2011) to 49% (Kolver and Muller, 1998) compared to cows under grazing without supplementation, and achieves 7–25% higher yields than cows on MD (Kennedy et al., 2015; Méndez et al., 2023). However, the response varies depending on parity, lactation stage, consumption, diet composition, pasture quality, and the energy demand associated with walking and grazing (Vibart et al., 2008). Feeding TMR in multiparous (**M**) cows in early lactation consistently enhances milk and solids yield compared to MD (Kolver and Muller 1998; Fajardo et al., 2015; Salado et al., 2018) due to an increased DMI and energy intake. In primiparous (**P**) cows, responses to different feeding strategies are inconsistent. Some studies report higher milk production with TMR compared to MD (Chilibroste et al., 2012), while others find no significant differences (Jasinsky et al., 2019). However, TMR has a positive impact on BCS, reproductive performance, and endocrine/metabolic profiles (Meikle et al., 2013b). Newly calved P cows under grazing conditions experienced a more severe negative energy balance compared to M cows (Meikle et al. 2004, Adrien et al. 2011) and faced difficulties adapting to grazing, reflected by low grazing activity and biting rates during pasture access (Chilibroste et al., 2012, Iqbal et al. 2022). Questions have arisen regarding the use of TMR in early lactation (Méndez et al., 2023), particularly concerning the direct and residual productivity responses, considering parity during the transition period. This highlights the need for a deeper understanding of how different feeding management during the transition period impacts animal performance.

Previous studies primarily report direct milk production responses when comparing TMR and pasture-based diets. According to a review (Jørgensen et al., 2016), only seven studies have explored the carryover effects of early lactation, focusing on concentrate levels and postgrazing height (Ganche et al., 2014). Studies have reported varied responses without considering parity as a factor, and none have made comparisons with TMR. The mechanisms underlying residual responses remain incompletely defined and operate at multiple levels (Jørgensen et al., 2016). When faced with dietary changes, cows can assess their environment and adapt to different feeding regimens by adjusting productive levels in response to ruminal and hepatic nutrient flow variations. This behavioural flexibility allows them to meet physiological needs (Delaby et al., 2009). Transitioning from TMR to pasture-based diets may further influence grazing behaviour, reflecting these adaptive responses.

To our knowledge, no previous research has exclusively focused on feeding during the transition period, considering direct and residual responses by parity and grazing adaptation. The hypotheses were as follows: (1) cows confined with TMR during the first 21 DIM (direct response), will increase milk and solids yield and BCS compared to an MD for P and M cows. (2) During the transition from TMR to MD, the differential milk production observed during the first 21 DIM will be sustained afterwards (residual effect). (3) Increasing grazing time will be one of the mechanisms to maintain milk production in cows switched from TMR to MD. Thus, an experiment was conducted to study the direct and residual productive responses and grazing adaptation during the initial 60 DIM of P and M Holstein dairy cows exposed to contrasting feeding management during the first 21 DIM.

Material and methods

Cows and experimental design

The study was carried out at the Experimental Research Station Dr. Mario A. Cassinoni of the Facultad de Agronomía, Universidad de la República (Paysandú, Uruguay; 32° S, 58° W). The study was replicated in two experiments based on the predominant calving seasons in Uruguay, autumn (experiment 1, from February to May 2021) and winter-spring (experiment 2, from June to October 2021) using a completely randomised block design. Before calving, cows were blocked according to lactation number, expected calving date, BW, BCS, and randomly assigned to the treatment groups. The treatments started immediately after calving and continued until 60 DIM, which comprised:

MD-MD: Cows fed a MD with grazing after a.m. milking (8 h access to paddock) and supplementation with mixed ration after p.m. milking, from calving until 60 DIM.

TMR-MD: Confined cows with TMR provided *ad libitum* during the first 21 DIM in a compost-bedded pack barn and switched to MD at 22 DIM and evaluated until 60 DIM.

Initially, 72 total Holstein dairy cows were allocated. Because of calving complications or serious illnesses (caesarean section, metritis, downer cow syndrome), 5 animals were removed from the experiment. This resulted in a final enrollment of 67 cows, equally distributed between two experiments (experiment 1: 20 M and 10P, experiment 2: 23 M and 14 P). Cows had a lactation number 2.0 ± 1.6 and 2.2 ± 1.4 (mean ± SE), BW 668 ± 89 and 622 ± 84 kg, BCS at calving 3.3 ± 0.3 and 3.3 ± 0.4 (scale 1 (skinny) to 5 (fat) (Ferguson et al., 1994), and calving date 11 April 2021 ± 20 days and 26 July 2021 ± 14 days for experiments 1 and 2, respectively.

All the cows had been exposed to pastures and had grazing experience as growing heifers and during their previous lactations. During the *prepartum* (21 days before parturition), the management was the same for all animals, and P cows were fed separately from M cows. They were offered a TMR diet composed of barley straw (experiments 1 and 2), corn (experiment 1), and sorghum (experiment 2) silage as a source of fibre and a *prepartum* commercial concentrate.

Feeding and grazing management

Cows in TMR-MD during the first 21 DIM were housed in a compost-bedded pack barn (13.2 m^2/cow) with automatic drinkers to ensure fresh water access, ventilation (fans), and sprinklers. The milk parlour was located 100 m from pens to minimise cow activity and long waiting periods during milking, which took place at 0500 and 1500 h. (for more details, see Méndez et al. 2023). Feeding access inside the barn was organised with galvanised sheet feeders along the front, providing 0.77 m/cow of space per cow on a concrete feeding area to reduce competition. The TMR was provided *ad libitum* once daily at 0800 h, ensuring 10% refusals (Brady et al., 2021). From DIM 22–60, TMR-MD cows joined the MD-MD treatment receiving the same feeding management and managed together.

Cows in MD-MD since calving and TMR-MD (22–60 DIM) had 7 h of daily access to weekly grazing plots after a.m. milking (from 0700–1400 h) and grazed together on annuals oats and raygrass pasture (*Avena sativa, Lolium multiflorum*), a second-year multispecies pasture with tall fescue (*Festuca arundinacea*), white clover (*Trifolium repens*) and birdsfoot trefoil (*Lotus corniculatus*), a third-year multispecies pasture with lucerne (*Medicago sativa*), and orchard grass (*Dactylis glomerata*), and biennial pasture with annual raygrass (*Lolium multiflorum*), and chicory (*Cichorium intybus*), located 1.7 km from the milking parlour with access to water in the pastureland.

The MD for MD-MD and TMR-MD (22–60 DIM) was formulated assuming that pasture availability was not limited (Table 1 and Table 2.), offering a herbage allowance three times higher than the expected DMI (25–30 kg DM/cow per day at ground level; Table 3). Grazing management followed a rotational system with weekly plot occupation. New plots were assigned based on herbage mass (kg DM/ha) and plant condition (e.g., number of leaves extended and/or nodes in lucerne) to ensure the target herbage allowance was consistently met (Table 3). After p.m. milking, cows were supplemented with a restrictive amount of mixed ration and remained in the same area overnight. In Experiment 1, cows were housed indoors in a compost-bedded pack barn under the previously specified conditions. In Experiment 2, cows remained in an outdoor soil-bedded yard with natural shade and water troughs.

Measures and samples analysis

Milk production was recorded individually, daily at each milking by the milk measurement system GEA Dairy Plan C21 (Version 5.3). Milk composition was evaluated from individual milk samples collected weekly in both experiments during two consecutive milkings. Fat, total protein, and lactose were determined by infrared (MilkoScan FossElectric FT2®, Drachten, The Netherlands). The energy in milk was calculated using the following equation:

$$\text{Energy in milk (Mcal/d)} = 0.0929 \times (\%\text{fat} + 0.0547 \times \%\text{protein} + 0.0395 \times \%\text{lactose}) \times \text{milk yield (L/d)}$$

Body condition score was visually recorded fortnightly in both experiments by the same observer using a 5-point scale with 0.25 increments (Ferguson et al., 1994).

To determine the appropriate paddock sizes for the target herbage allowance of 25–30 kg DM/cow per day at ground level, herbage mass (kg DM/ha) was estimated weekly in both experiments using a double-sampling technique adapted from Haydock and Shaw (1975). This method utilised a 3-point calibration scale and three replicates for each sampling level. Weekly, three replicate sets of 30 cm × 30 cm pasture squares were selected from each of the three sampling locations (low, medium, and high) within the grazing areas. In each square (totaling six), herbage was measured with a sward stick (Barthram, 1986), cut at ground level, collected, weighed, and sampled for DM content determination. Sward height was then measured in a zigzag pattern every five

Table 1
Ingredient composition (% of DM) of TMR and mixed ration fed to dairy cows.

	Experiment 1			Experiment 2		
Response[1]	Direct		Residual	Direct		Residual
Treatments[2]	MD-MD	TMR-MD	Both	MD-MD	TMR-MD	Both
Ingredients, % of DM						
Corn silage	34.0	36.6	43.9	15.0	44.3	16.4
Sorghum silage	–	–	–	27.6	–	24.3
Moha hay	2.1	6.3	0.8	1.7	4.6	–
Corn grain	17.9	22.0	15.5	19.1	17.4	21.0
Soybean meal	9.6	9.8	8.3	10.5	11.7	7.2
Canola meal	–	7.3	–	–	5.8	
Sunflower expeller	–	5.2	–	–	5.8	
Soybean hulls	–	9.8	–	–	7.7	
Wheat bran	24.6	–	21.3	22.7		24.1
Corn dried distillers' grain with soluble	9.6	–	8.3	–		3.1
Minerals and vitamins	2.2	2.5	1.9	3.7	2.5	3.9
Forage:concentrate ratio	36:64	43:57	45:55	44:56	49:51	41:59

Abbreviations: TMR = total mixed ration; MD = mixed diet; DIM = days in milk.
[1] Response: direct (weeks 1–3) and residual (weeks 4–9).
[2] Treatments: MD-MD = cows fed a MD from calving until 60 DIM, TMR-MD = confined cows fed with TMR provided *ad libitum* during the first 21 DIM and then moved to MD from 22 to 60 DIM.

Table 2
Chemical composition (% of DM) and offer of the TMR and mixed ration fed to dairy cows by treatment and response.

	Experiment 1			Experiment 2		
Response[1]	Direct		Residual	Direct		Residual
Treatments[2]	MD-MD	TMR-MD	both	MD-MD	TMR-MD	both
% of DM						
DM	58.3 ± 2.3	53.3 ± 4.4	60.1 ± 0.2	40.1 ± 2.1	50.2 ± 2.4	45 ± 4.1
CP	14.7 ± 2.3	17.0 ± 1.2	14.3 ± 0.2	14.3 ± 0.05	17.1 ± 0.3	14.3 ± 0.4
NDF	34.5 ± 1.1	35.5 ± 1.5	34.5 ± 0.3	39.2 ± 1.6	36.5 ± 1.8	40.0 ± 1.7
ADF	12.8 ± 1.8	17.1 ± 1.4	12.8 ± 0.3	17.6 ± 1.0	18.9 ± 1.6	17.4 ± 0.5
Ash	7.1 ± 0.3	7.9 ± 0.4	7.1 ± 0.2	9.1 ± 0.1	7.5 ± 0.4	9.9 ± 0.9
NEL (Mcal/kg DM)[3]	1.72 ± 0.03	1.65 ± 0.04	1.72 ± 0.01	1.64 ± 0.02	1.62 ± 0.05	1.65 ± 0.01
Allowance (kg DM/cow per day)[4]	12.6 ± 0.4	29.0 ± 1.2	14.1 ± 1.2	13,3 ± 0.5	29.9 ± 3.5	13.1 ± 0.8

Abbreviations: TMR = total mixed ration; MD = mixed diet; NEL = net energy of lactation; DIM = days in milk.
[1] Response: direct (weeks 1–3) and residual (weeks 4–9).
[2] Treatments: MD-MD = cows fed a MD from calving until 60 DIM; TMR-MD = confined cows fed with TMR provided *ad libitum* during the first 21 DIM and then moved to MD from 22 to 60 DIM.
[3] Estimated net energy of lactation calculated as 1.909 – (0.017 × ADF) according to NRC.
[4] Corresponds to the amount of mixed ration intake, as indicated by the empty feeders each morning for the MD-MD group during both the direct and residual periods, and for the TMR-MD group during the residual period.

Table 3
Chemical composition and characteristics of the pasture offered to dairy cows by to treatment and response.

	Experiment 1		Experiment 2	
Response[1]	Direct	Residual	Direct	Residual
Treatments[2]	MD-MD	Both	MD-MD	both
Herbage allowance, kg DM/cow per day	27.5 ± 4.3	24.4 ± 4	27.6 ± 0.6	27.1 ± 4.5
Pregrazing herbage mass, kg DM/ha	2 824 ± 682	2 054 ± 426	2 090 ± 535	2 128 ± 372
Postgrazing herbage mass, kg DM/ha	1 220 ± 635	1 166 ± 635	1 533 ± 714	1 481 ± 363
Pregrazing sward height, cm	17.7 ± 1.3	23.4 ± 1.3	24.2 ± 7.0	21.1 ± 4.1
Postgrazing sward height, cm	12.1 ± 0.8	14.3 ± 4.4	13.5 ± 1.3	14.5 ± 1.3
% of DM				
DM	25.3 ± 2.5	20.8 ± 4.6	23.7 ± 3.3	22.4 ± 4.1
CP	15.9 ± 4.0	21.3 ± 3.1	20.6 ± 4.3	18.7 ± 4.1
NDF	54.6 ± 8.4	39.3 ± 8.5	34.1 ± 7.1	36.1 ± 2.6
ADF	25.4 ± 2.7	17.2 ± 2.4	16.4 ± 3.0	17.6 ± 2.0
Ash	11.6 ± 1.4	12.1 ± 8.0	11.3 ± 1.4	11.3 ± 1.4
NEL (Mcal/kg DM)[3]	1.54 ± 0.06	1.73 ± 0.06	1.66 ± 0.03	1.64 ± 0.03

Abbreviations: MD = mixed diet; TMR = total mixed ration; NEL = net energy of lactation; DIM = days in milk.
[1] Response: direct (weeks 1–3) and residual (weeks 4–9).
[2] Treatments: MD-MD = cows fed a MD from calving until 60 DIM; TMR-MD = confined cows fed with TMR provided *ad libitum* during the first 21 DIM and then fed with MD from 22 to 60 DIM.
[3] NEL: Estimated net energy of lactation using (2.301 – (0.0289 × %ADF)) × 4.1868 × 0.239 (Acosta, 2004).

steps within the paddock using the sward stick. A linear regression relating sward height to DM mass from the calibration allowed for the determination of the mean herbage mass within the paddock.

Grazing behaviour (grazing and ruminating time during the grazing session) was measured individually, daily in both experiments in all the cows with Boumatic® devices fixed on a collar and placed around the cow's neck. These collars have been previously validated for Uruguayan dairy production systems (Fast et al., 2021).

The offer of TMR and mixed ration was recorded daily, in both experiments and representative samples of pasture, mixed ration, TMR, and components (silages, concentrate, and hay) were taken weekly in both experiments. The samples were weighed and oven-dried at 60 °C for 72 h to determine DM content. For pasture, the samples were obtained manually, simulating the residual sward height left by the cows. Samples were milled at 1 mm, and in each experiment, pooled and analysed monthly (TMR, mixed ration, and feedstuffs), except for pasture samples, which were analysed according to the different pastureland resources and paddocks. CP, NDF, and ADF were determined according to AOAC (2000). Total N for CP estimation used the Kjeldahl method of AOAC (1984), which involves sulfuric acid digestion with subsequent distillation and titration. NDF used amylase, and, as for ADF, an ANKOM200 Fiber Analyzer (ANKOM Tech. Corp., Fairport, NY, USA) was used.

Statistical analysis

Data were analysed in a randomised complete block design using the REPEATED statement in the MIXED procedure of SAS (SAS Institute Inc., Cary, NC, USA). For all variables, the cow, nested within the treatment and experiment, was used as the experimental unit. To study the impact of feeding management, the variables were analysed for the total response (weeks 1–9), direct response (weeks 1–3) during the application of contrasting feeding management, and residual response (weeks 4–9) to evaluate carryover effects when treatments were managed together. The models used were:

Milk production (total response, weeks 1–9):

$$Yij = \mu + T_i + P_k + WL_l + (T \times P \times WL)_{ikl} + B_j + \varepsilon_{ijkl}$$

where Yij is milk production, μ is the overall mean, T_i denotes the fixed effect of treatment (i = MD-MD or TMR-MD), P_k is the parity effect (k = M or P), WL_l denotes the week of lactation, $(T \times P \times WL)_{ijkl}$ is the fixed effect of the interaction, B_j refers to block as a random effect, and ε_{ijkl} denotes the residual error.

Milk production and composition (direct response weeks 1–3, residual response weeks 4–9):

$$Yij = \mu + T_i + P_k + (T \times P)_{ik} + B_j + \varepsilon_{ijk}$$

where Yij is milk production and all variables for milk composition, μ is the overall mean, T_i denotes the fixed effect of treatment (i = MD-MD or TMR-MD), P_k is the parity effect (k = M or P), $(T \times P)_{ijk}$ is the fixed effect of the interaction, B_j refers to block as a random effect and ε_{ijk} denotes the residual error.

Body condition score was analysed based on both the direct response during weeks 1–3 and the residual response from weeks 4 to 9. Additionally, two delta (**Δ**) values were assessed: the difference between BCS at calving and BCS at 21 dpp, and the difference between the average BCS during the direct response period and the residual period.

$$Yij = \mu + T_i + P_k + (T \times P)_{ik} + \mathrm{CO} + B_j + \varepsilon_{ijk}$$

where Yij is body condition score, μ is the overall mean, T_i denotes the fixed effect of treatment (i = MD-MD or TMR-MD), P_k is the parity effect (k = M or P), $(T \times P)_{ijk}$ is the fixed effect of the interaction, CO is the BCS at calving used as a covariate, B_j refers to block as a random effect and ε_{ijk} denotes the residual error.

Grazing behaviour (residual response weeks 4–9):

$$Yij = \mu + T_i + P_k + WL_l + (T \times P \times WL)_{ikl} + \mathrm{C} + B_j + \varepsilon_{ijkl}$$

where Yij is grazing and rumination time, μ is the overall mean, T_i denotes the fixed effect of treatment (i = MD-MD or TMR-MD), P_k is the parity effect (k = M or P), WL_l is the week of lactation. $(T \times P)_{ijk}$ and $(T \times P \times WL)_{ikl}$ is the fixed effect of the interaction, C is access time to the paddock day used as a covariate to appropriately account for differences across days, B_j refers to block as a random effect, and ε_{ijk} denotes the residual error.

The values reported are least-square means and SEs of least-square means. The model (co)variance structure was selected based on the smallest Bayesian information criterion value. Statistical significance was assumed at $P < 0.05$, and a tendency toward significance was assumed at $P \geq 0.05$ but <0.10. Results are shown as the mean ± SEM.

Results

Productive response

Overall response (1–9 weeks of lactation)

Cows fed a TMR in the first 21 DIM produced significantly more milk than cows in a pasture-based system (34.1 vs 32.9 L/d, P = 0.0057, TMR-MD and MD-MD, respectively). The triple interaction between treatment, parity, and week of lactation indicated that the evolution of milk production differed significantly (Fig. 1, P = 0.01). Specifically, M TMR-MD cows exhibited higher milk yield compared to M MD-MD cows at weeks 2 and 3. At week 2, M TMR-MD cows produced 39.2 L/d compared to 33.2 L/d for M MD-MD cows (P = 0.0004). At week 3, M TMR-MD cows peaked significantly higher, producing 41.0 L/d compared to 35.3 L/d for M MD-MD cows (P = 0.0001). The switch of M TMR-MD cows to the MD did not result in a significant decline in milk yield within the treatment (41.0 L/d at week 3 vs 39.6 L/d at week 4; P = 0.99). The residual response mainly occurred in the first 3 weeks after the switch, with M TMR-MD cows maintaining milk production. As lactation progressed, the milk yield curves of both treatments gradually converged (Fig. 1).

Feeding P cows with TMR after calving resulted in a numerical increase in milk production compared to those with MD, but the difference was not statistically significant. Primiparous cows peaked at 29.8 and 27.8 L/d at week 3 for TMR-MD and MD-MD, respectively (P = 1.0). The switch in P cows consuming TMR to MD did not result in statistically significant differences within the treatment (29.8 L/d at week 3 vs 28.5 L/d at week 4, P = 1.0), and the lactation curves evolved similarly between treatments (Fig. 1).

Direct response (0–3 weeks of lactation)

Cows fed TMR exhibited an 11% increase compared to those with MD (33.4 vs 29.9 L/d for TMR-MD and MD-MD, respectively, P = 0.006, Table 4). Additionally, the M cows produced significantly more milk than the P cows (36.4 vs 26.9 L/d, respectively, P < 0.0001). An interaction between treatment and parity was observed (P = 0.004), where M TMR-MD cows presented higher milk yield than M MD-MD (39.5 vs 33.3 L/d, P = 0.0003), while no significant differences were detected between P (27.2 and 26.6 L/d for TMR-MD and MD-MD, respectively, P = 0.98).

Feeding TMR affected fat concentration during the first 3 weeks (Table 4, P = 0.029) but not lactose and protein concentrations. Protein yield was higher and fat yield tended to increase in TMR-MD

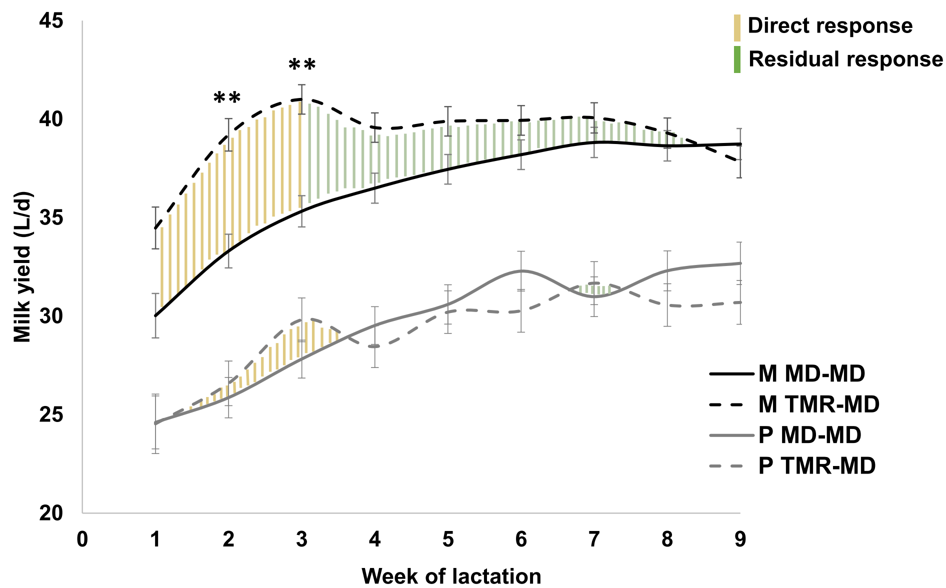

Fig. 1. Evolution of milk production in dairy cows under contrasting feeding management during the first 21 DIM (mixed diet (MD) and total mixed ration (TMR)) and by parity (multiparous (M) and primiparous (P)). Error bars represent the SE of the mean. Statistical significance is indicated by * ($P \le 0.05$), and ** ($P \le 0.01$) between treatments inside the parity in a particular week.

Table 4
Milk production, composition, and BCS in dairy cows under contrasting feeding management during the first 21 DIM, according to the direct and residual response.

Response[1]	Variable	Treatments[2]		SEM	*P*-value		
		MD-MD	TMR-MD		T	P	T × P
Direct	Milk yield, L/d	29.9[b]	33.4[a]	1.21	0.006	<0.0001	0.024
	Fat, %	3.59[b]	4.10[a]	0.22	0.029	0.705	0.864
	Fat, kg/d	1.11	1.33	0.12	0.074	0.002	0.274
	Protein, %	3.61	3.60	0.08	0.993	0.643	NE
	Protein, kg/d	1.19[b]	1.32[a]	0.06	0.034	0.085	NE
	Lactose, %	5.05	4.96	0.07	0.179	0.717	0.631
	Lactose, kg/d	1.53	1.55	0.10	0.795	<0.0001	0.042
	Energy in milk, Mcal/d	24.5[b]	28.6[a]	1.41	0.006	0.0002	NE
	BCS, mean	3.10	3.18	0.05	0.140	0.072	0.271
	ΔBCS (0 to 21 DIM)	−0.10	−0.02	0.05	0.149	0.088	0.293
	ΔBCS (21 to 60 DIM)	−0.23	−0.20	0.04	0.527	0.025	0.215
Residual	Milk yield, L/d	34.8	34.9	0.45	0.765	<0.0001	0.005
	Fat, %	3.51	3.76	0.14	0.071	0.170	0.020
	Fat, kg/d	1.22	1.24	0.07	0.747	0.0002	0.308
	Protein, %	3.26[b]	3.37[a]	0.05	0.025	0.005	<0.0001
	Protein, kg/d	1.09	1.12	0.05	0.477	<0.0001	0.066
	Lactose, %	5.13	5.12	0.05	0.804	0.0007	0.601
	Lactose, kg/d	1.71	1.72	0.08	0.857	<0.0001	0.650
	Energy in milk, Mcal/d	25.5	25.3	0.94	0.835	<0.0001	0.344
	BCS, mean	2.86	2.96	0.04	0.025	0.736	0.546

Abbreviations: TMR = total mixed ration; MD = mixed diet; T = treatment; P = parity; NE = no estimated; BCS = body condition score; DIM = days in milk.
[1] Response: direct (weeks 1–3) and residual (weeks 4–9).
[2] MD-MD: cows fed a MD from calving until 60 DIM, TMR-MD: confined cows fed with TMR provided *ad libitum* during the first 21 DIM and then fed with MD from 22 to 60 DIM.
[a,b] Within rows, mean values that do not share superscripts differ significantly from each other ($P < 0.05$).

compared to MD-MD without treatment effect on lactose yield. A tendency for higher protein yield ($P = 0.085$) in M than in P was also found. Cows in TMR-MD had higher energy in milk than MD-MD ($P = 0.006$) and M cows than P cows ($P = 0.0002$). The differential feeding management does not imply differences in BCS either between treatments (3.2 vs 3.1 for TMR-MD and MD-MD, respectively $P = 0.13$) or within parity.

Residual response (4–9 weeks of lactation)

No significant differences in milk production were detected between treatments (34.9 vs 34.8 L/d for TMR-MD and MD-MD, respectively; $P = 0.765$) after changing from TMR-MD to MD. However, there was a significant interaction between treatment and parity, indicating that M TMR-MD cows exhibited higher milk production than M MD-MD (39.5 vs 38.0 L/d, respectively, $P = 0.04$) which was not found for P cows (TMR-MD = 30.3 and MD-MD = 31.4 L/d, $P = 0.41$). Furthermore, similarly to the direct period, milk production differed according to parity (M = 38.7 and P = 30.9 L/d, $P < 0.0001$).

A trend was observed for fat concentration ($P = 0.071$) in TMR-MD cows, with an interaction between treatment and parity. A tendency for higher fat concentration in P TMR-MD than in P MD-MD

(4.02 vs 3.43% for P TMR-MD and P MD-MD, respectively, *P* = 0.057) was also observed. TMR-MD cows presented a higher protein concentration in milk than MD-MD cows (*P* = 0.025). In addition, an interaction between treatment and parity was observed for protein. This resulted in differences between P cows (3.54 vs 3.22% for TMR-MD and MD-MD, respectively, *P* = 0.0007) but not between M cows. For the same component, there was a significant parity effect (3.38 vs 3.24% for P and M, respectively, *P* = 0.005). For lactose, only the parity effect was detected as significant where P cows presented higher concentrations of lactose than M cows (5.20 vs 5.04% for M and P, respectively, *P* = 0.0007). Despite the differences in milk components, fat, protein, and lactose yields did not differ among treatments. For energy in milk, only the parity effect was detected as significant. TMR-MD cows achieved a higher BCS than MD-MD (3.0 vs 2.9, respectively, *P* = 0.03), without an effect of parity (*P* = 0.18) or the interaction between treatment and parity (*P* = 0.54). Body condition score change from calving to 21 DIM showed no treatment differences (Table 4), with a tendency for M cows to lose more BCS than P cows. Similarly, BCS change between direct and residual periods was consistent across treatments (Table 4), but M cows experienced a significantly greater BCS loss than P cows (−0.27 vs −0.16, respectively, *P* = 0.02).

Grazing and rumination evolution

Cows that started grazing immediately after calving (MD-MD), regardless of parity, showed an increase in grazing time as DIM progressed (Fig. 2). In M MD-MD cows, the highest increase was at week 5, rising from 44% in the first week to 52% of paddock access time (533 ± 70 min/d). Primiparous MD-MD cows showed the highest increase at week 6, rising from 43% in the first week to 51% of paddock access time at week 6. Rumination time increased in both groups from calving to week 3 followed by stabilisation as lactation progressed.

When TMR-MD cows started grazing (weeks 4–9) and treatments were managed together, no differences were found between treatments in grazing (TMR-MD: 254 vs MD-MD: 261 min/d, *P* = 0.186) or rumination time (TMR-MD: 128 vs MD-MD: 125 min/d, *P* = 0.406), representing 48 and 24% of paddock access time, respectively. A parity effect was detected for both variables: M cows spent more time grazing (M: 265 vs P: 250 min/d, *P* = 0.0034) and ruminating (M: 132 vs P: 123 min/d, *P* = 0.005) compared to P cows. A significant interaction between treatment and parity was observed for grazing time (*P* = 0.05) but not for rumination time (*P* = 0.66). Differences were found between treatments and parities (M MD-MD: 263 min/d vs P TMR-MD: 243 min/d, *P* = 0.01) and within TMR-MD (M TMR-MD: 266 min/d vs P TMR-MD: 243 min/d, *P* = 0.004). The triple interaction was non-significant for grazing time (*P* = 0.144), but it was significant for rumination time (*P* = 0.002); however, no differences were detected between treatments or within parity groups at any week.

Author's point of views

Direct response (0–3 weeks of lactation)

The increased milk yield in M cows aligns with previous studies comparing TMR and MD feeding during early lactation (Fajardo et al., 2015), mainly due to higher DMI and lower energy expenditure (Kolver and Muller, 1998). In the present study, M cows fed TMR may have achieved higher DMI due to the *ad libitum* offer and confined infrastructure, compared to MD cows. The optimal NDF content of the TMR, which enhances DMI (Mertens, 1994), may have further contributed to higher energy intake (Salado et al., 2020). Moreover, the lack of energy expenditure from walking, searching, and grazing (Bargo et al., 2002) likely contributed to redirecting energy from maintenance toward milk production. For cows with a pasture-based diet, factors such as suboptimal rumen fermentation (Bargo et al., 2002), grazing time, and bite rate may limit nutrient intake and thus contribute to explain the difference in milk yield compared to cows consuming TMR (Kolver and Muller 1998). This, combined with the onset of lactation, suggests a behavioural adaptation process in grazing. The gradual increase in grazing time during the postpartum period is associated with the rise in herbage intake and total DMI (Bossen et al. 2009).

Studies comparing TMR and MD typically evaluate longer periods, ranging from calving to 60 DIM (Fajardo et al., 2015) or even across full lactation (Salado et al., 2020; Méndez et al., 2023). Only 2 studies have focused on differential feeding management in the first 4 weeks *postpartum*. Al Ibrahim et al. (2013) investigated the effects of differential diets over the first 100 DIM (TMR vs MD) during the first 21 DIM. They found that confined cows had a higher DMI (approximately 1 kg DM), but there were no significant differences in milk yield, primarily due to the restricted TMR offer (23 kg DM/d). However, their analysis examined the entire experimental period without distinguishing between direct and residual responses. When shorter-term dietary interventions are evaluated over long periods, the dilution effect can hide differences, making them statistically undetectable. Brady et al. (2021) evaluated similar dietary interventions in cows of mixed parity, comparing *ad libitum* TMR during the first 30 DIM with grazing and supplemented with 3 kg DM/d of concentrate, and found no significant differences in milk production. The authors attributed this lack of significance to small differences in DMI between treatments (0.5 kg DM/d), as well as low protein (15.5% DM basis) and starch levels (20.1% DM basis) in the TMR. The DMI values found in both studies range between 17 and 18 kg DM/d using the Holstein Friesian strain. In contrast, the present work used the North American strain, the same herd as Fajardo et al. (2015), which reported that cows fed TMR achieved a DMI of 26 kg DM/d at 4- and 5-weeks *postpartum*. The lower DMI in confined cows along with differences in ingredients, quality, and energy content might explain the lack of response observed in the previously mentioned studies. Nevertheless, the present study shows that offering M cows with *ad libitum* access can significantly improve milk production, suggesting as a strategic approach for achieving peak production in dairy systems.

In P cows, the lack of differences between treatments was unexpected. A 21-day full TMR feeding was anticipated to increase milk yield due to the adaptation challenges faced under grazing conditions at the beginning of lactation (Chilibroste et al., 2012), compared to M cows (Meikle et al., 2013a). Moreover, a recent study by Walsh et al. (2024) found that P cows had a lower increase in DMI compared to M cows (0.41 vs 0.49–0.55 kg DM/d) under grazing conditions. The authors indicated that a higher increase in DMI is expected when cows are fed *ad libitum*, suggesting that P cows may be more productive under high-feed conditions than in pasture-based systems. Meikle et al. (2013a,b) found higher milk production in P cows fed TMR compared to those on MD with different herbage allowance levels. Since similar responses were expected for P cows fed TMR, it is possible that the non-detection of differences was due to the higher level of supplementation in this study (MD-MD) compared to that reported by Meikle et al. (2013a,b). Other authors (Ceriani et al., 2018; Jasinsky et al., 2019) assessed two feeding strategies during early lactation in P cows: TMR vs MD (grazing with 70% of *ad libitum* TMR). They observed a trend of higher milk yield in the TMR group, with no significant differences in DMI between the feeding strategies. As supplementation levels increase, milk production in cows on MD improves and becomes similar to that of TMR cows, which makes it difficult to detect differences between the two feeding strategies. A study by Gaillard et al. (2016) evaluated high or low-energy diets

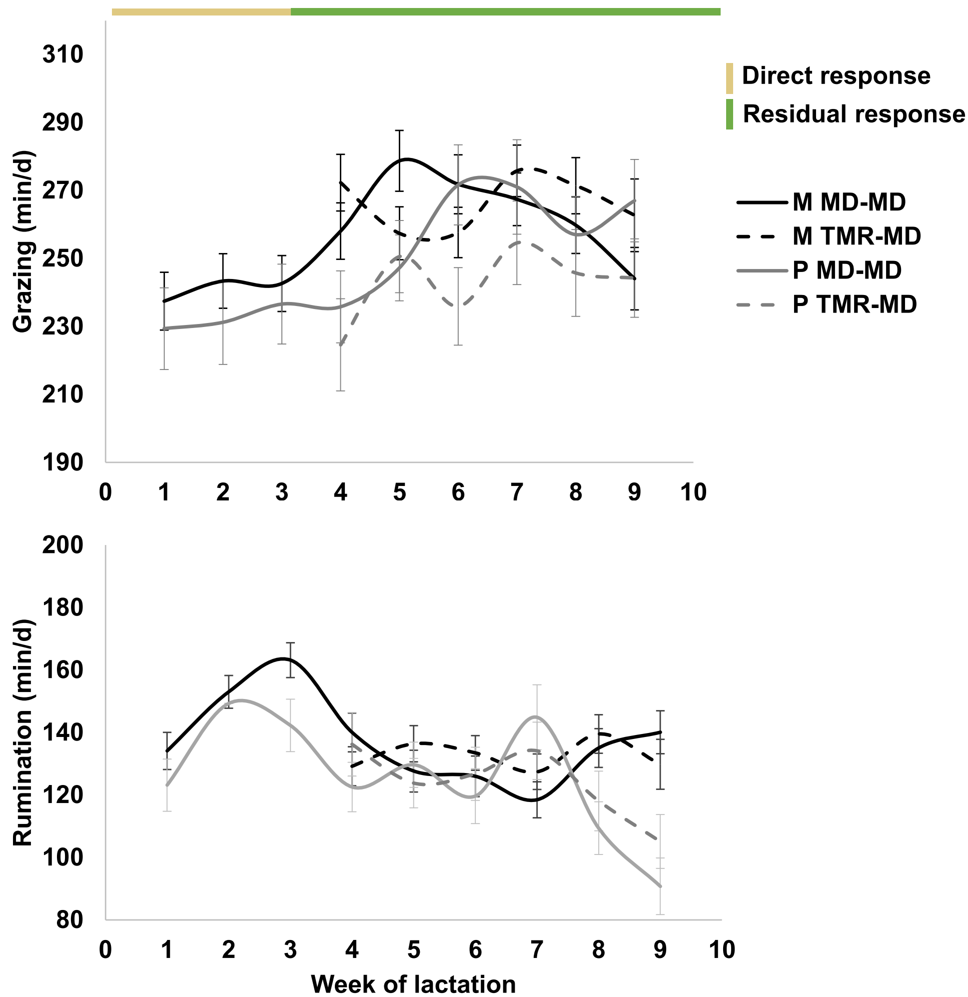

Fig. 2. Evolution of grazing and ruminating time at pasture in dairy cows under two different feeding management during the first 21 DIM (mixed diet (MD) and total mixed ration (TMR)) and by parity (multiparous (M) and primiparous (P)). Error bars represent the SE of the mean.

in the first 40 DIM in P cows and found that the extra energy was used for growth and body reserves, not for increased milk yield. In this experiment, differences in BCS were difficult to detect over a short period. It seems that a 21-day feeding TMR is insufficient for P cows, which require additional time to adapt to the new feeding regimen and daily routine to show a treatment response.

Residual response (4–9 weeks of lactation)

Switched M cows from TMR to MD allowed them to sustain higher production until 60 DIM, with the carryover response mainly in the first 3 weeks following the diet change. The causes may involve multiple mechanisms such as energy partitioning (Kennedy et al., 2007; Jørgensen et al., 2016), alveoli dynamics (Nørgaard et al., 2005; Ganche et al., 2014), and behavioural changes in eating patterns (Roche, 2007; Capuco and Choudhary, 2020). In M cows previously fed a high-energy diet during the first 40 DIM and then switched to a low-energy diet (Gaillard et al., 2016), higher DMI, energy intake, and milk production were observed in the first week after the change, indicating a short-term carryover effect. This study hypothesised that the residual response might be due to increased grazing time. However, the lack of differences in grazing and rumination time between treatments suggests that any potential increase in energy intake may result from other mechanisms, such as changes in pasture selectivity (Menegazzi et al., 2021). Mobilisation of body reserves does not appear to contribute to this response, as indicated by the higher BCS in TMR-MD cows.

Despite the abrupt dietary change from full TMR to a pasture-based diet, cows adapted rapidly and successfully to grazing, performing at levels to cows that had already been adapted since calving (MD-MD). In contrast, other studies have reported negative effects on animal performance when transitioning from TMR to a pasture-based system (Schären et al., 2016; Hartwiger et al., 2018) indicating a complex nutritional, behavioural, and metabolic adaptation. A gradual introduction to the MD system (grazing plus 4.5 kg DM of concentrate supplementation) from TMR resulted in a 12% decrease in milk yield in mixed-parity cows during mid-lactation (Hartwiger et al., 2018). Similar results were reported by (Schären et al., 2016) with a greater decrease (15–17%) due to the lower supplementation level (1.75 kg DM of concentrate/d). The magnitude of pre- and postfeeding and its duration are the most determining factors in residual productive responses (Jørgensen et al., 2016). As reported in previous studies, large changes in the quantities offered have a negative impact. In the present research, the shift from TMR to MD involved a high level of supplementation (13–14 kg DM/d) that represented 54–59% of the DMI (estimation based on energy balance, not reported) and optimal pasture conditions (2000–2100 kg DM/ha and 21–23 cm height). This combination minimised the impact on milk production and BCS (Fajardo et al., 2015). Over long analysis periods (+100 days), the residual response is diluted, as it primarily occurs in the short term, particularly during the initial weeks following a diet change. Most studies either covered extended residual periods where potential responses were undetectable (Kennedy et al., 2015) or did not evaluate residual responses (Al Ibrahim et al., 2013; Brady et al., 2021), where these responses are likely to occur. The findings of this study highlight the importance of analysing variables by period to capture residual responses and accurately estimate the total economic impact of a feeding strategy (Jørgensen et al., 2016).

Contrary to the findings in M cows, transitioning P cows to a MD at 22 DIM (TMR-MD) may not be advisable. Although P cows adapted well to grazing, performing at the same level as MD-MD cows, the transition to a new feeding strategy appears to have triggered tissue mobilisation. This is evidenced by higher milk concentrations of protein and fat (trending) compared to P cows that had already been adapted to grazing since calving (MD-MD). This category appears to be sensitive to feeding changes due to their ongoing adaptation to new management. Primiparous cows have additional requirements, as they are still growing, and the demands of lactation coincide with their growth requirements (Wathes et al., 2007). Further research is required to fully understand the mechanisms underlying these residual responses.

Conclusions

Implementing an *ad libitum* TMR strategy during the first 21 DIM in a confinement system, followed by a transition to a pasture-based diet, yielded parity-specific responses in productive performance. Multiparous cows exhibited immediate higher responses in milk yield with carryover effects, and adapted successfully to the pasture-based diet, suggesting a potential strategy for achieving peak production. In contrast, this dietary intervention did not enhance the productive performance of P cows, indicating that an extended TMR period may be needed to reveal their full productive potential. However, P cows in a pasture-based system with high supplementation successfully met their nutritional demands, supporting and optimising milk yield during early lactation. The lack of differences in BCS between dietary interventions in both parities underscores the need for further research on metabolic adaptation during this period, particularly in P cows. Additional studies on early DMI, grazing adaptation, and carryover effects may provide valuable insights for optimising transition management in pasture-based systems.

Peer Review Summary

Peer Review Summary for this article (https://doi.org/10.1016/j.anopes.2025.100092) can be found at the foot of the online page, in Appendix A.

Ethics approval

The experimental protocol was evaluated and approved by the Comisión Honoraria de Experimentación Animal (CHEA), Universidad de la República, Montevideo, Uruguay (Expe # 020300-000693-20).

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) did not use any AI and AI-assisted technologies.

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Declaration of interest

None.

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