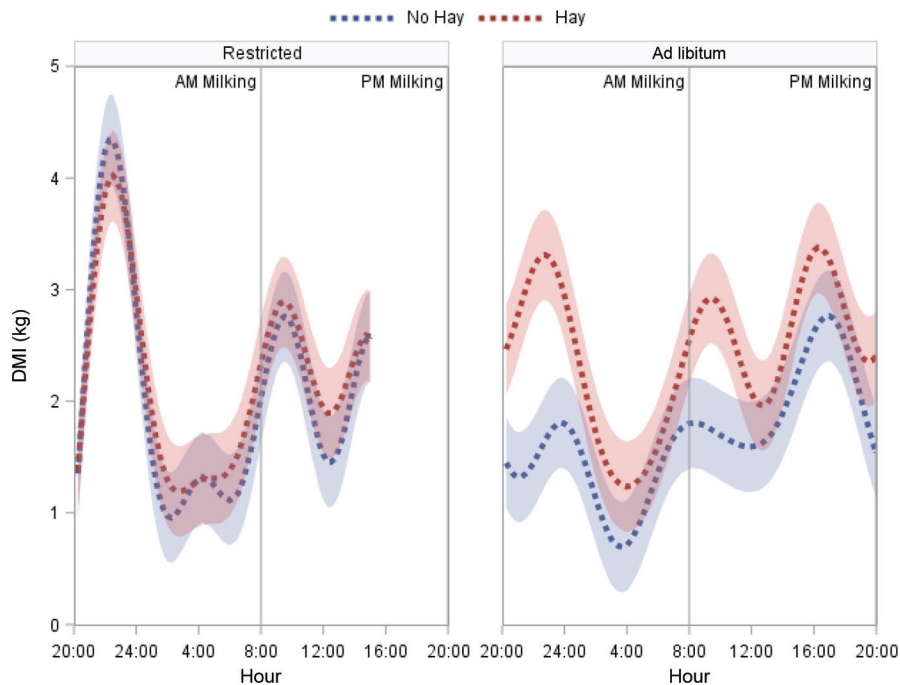


Limiting total mixed ration availability alters eating and rumination patterns of lactating dairy cows

A. J. Heinrichs,^{1*} B. S. Heinrichs,¹ D. Cavallini,² M. Fustini,² and A. Formigoni²

Graphical Abstract

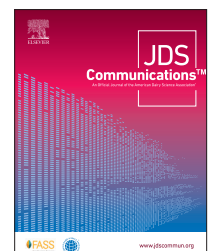


Summary

Limiting total mixed ration (TMR) availability from 24 to 19 h/d changed the eating patterns of lactating dairy cows. Availability of ad libitum hay also made a significant difference in dry matter intake (DMI) patterns, as shown by the 95% confidence limits in the shaded bands. Rumen pH pattern throughout the day was modified in restricted-fed cows, but ranges in values were similar to those of ad libitum-fed cows. The changes in intake patterns over time indicate that when feeding TMR diets, cows can adjust to the changes in feed availability and access to long hay.

Highlights

- Limiting TMR availability for 5 h/d changed the eating and rumination patterns of lactating dairy cows.
- Availability of ad libitum hay made a significant difference in DMI patterns.
- Daily rumen pH pattern was modified in restricted-fed cows, but ranges in values were similar to those of ad libitum-fed cows.
- When feeding very finely chopped diets, cows adjusted to the changes in feed availability and access to long hay.



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Limiting total mixed ration availability alters eating and rumination patterns of lactating dairy cows

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Abstract: The objective of this study was to investigate the effect of restricting total mixed ration (TMR) eating time with or without supplemental long hay offered on diurnal total intake, rumination, and rumen pH patterns in mid-lactation dairy cows. Eight multiparous Holstein cows were used in a replicated 4 × 4 Latin square design study with 21-d periods. The basal diet was the same for all 4 treatments with or without additional long grass hay (the same hay used in the TMR). For cows on limited-time TMR, diets were taken away at 1500 h (5 h before evening milking and feeding), and dry matter intake (DMI), ruminating, and rumen pH were monitored and summarized every 10 m for 7 d in each period. With restricted feeding, cows changed DMI patterns by consuming a large meal after feed was reinstated, resulting in lower DMI. Ruminating patterns closely mirrored intake patterns, as could be expected. Rumen pH was not different between groups but resulted in different diurnal patterns due to differences in eating and rumination patterns between the groups. Limiting feed availability can be used to change eating and rumination patterns, resulting in different rumen pH patterns.

It is generally established that dairy cows exhibit diurnal variation in many patterns of digestion and metabolism, with more eating during the day and more rumination at night (Schirmann et al., 2012). Many aspects related to cow behaviors and physiology are regulated by circadian rhythms, which coordinate the cow's physiology with its external environment, including feeding and milking routines. Rumination also appears to exhibit diurnal variation when animals are held under constant lighting conditions (Gordon and McAllister, 1970). Rumen pH follows similar diurnal patterns, with a gradual decrease during the day after the morning feeding and a lesser decrease after the larger evening feeding, followed by a gradual increase overnight (Beauchemin et al., 1990). The diurnal variations in pH and eating are almost inverse, likely demonstrating the effect of fermentable carbohydrates being more available during the day after the larger meals (Beauchemin et al., 1990; Schirmann et al., 2012). Attempts to spread out this pH fluctuation by feeding high-forage diets during the day and diets higher in carbohydrates in the evening have not been successful, as cows modified their feeding behaviors (Ying et al., 2015). In addition, studies have looked at altering these patterns of rumination and rumen pH by modifying fiber, starch type, and amount as well as content and source of fat with little effect (Salfer et al., 2018). Other studies have shown that cows appear to have the ability to modify their feeding behavior with rumen pH changes. Keunen et al. (2002) showed that lactating dairy cows with induced SARA increased their preference for long alfalfa hay over pelleted hay. Studies have shown that diet preferences changed as a result of low rumen pH (Maulfair et al., 2013; Kmicikewycz and Heinrichs, 2014), where cows had the ability to select for TMR of different particle sizes or long hay. The cows altered their physically effective fiber intake during a bout of SARA and later reverted to previous intake behaviors when rumen pH was more normal (Maulfair et al., 2013). However, environmental conditions and forage and

feed types may negate the effect of low rumen pH on feed preference (Cooper et al., 2002; Salfer et al., 2018).

Cavallini et al. (2018) evaluated the physiological and production responses of cows that were fed a TMR for 19 or 24 h with or without supplemental long dry hay to improve the feed efficiency of the limit-fed diet. Few production differences were observed once cows adapted to diet feeding regimens. However, consistent with other recent studies (Ben Meir et al., 2019), ECM feed efficiency was slightly improved in cows that had access to feed 19 versus 24 h/d due to slightly lower DMI.

The objective of the current study was to evaluate feeding and rumination behavior responses throughout the day and the resulting rumen pH patterns when cows were fed a restricted or ad libitum diet with or without supplemental long hay. This study was conducted at the University of Bologna (Italy), and all experimental procedures involving animals was approved by the University of Bologna Animal Care and Use Committee. Eight multiparous Holstein cows blocked by parity, milk production, and DIM were placed in a replicated 4 × 4 Latin square design study with 21-d periods, which included a 14-d adaptation period and a 7-d collection period. At the beginning of the trial, average parity was 2.25 ± 0.46, average milk production was 44.9 ± 2.5 kg/d, average DIM was 99 ± 49 d, and average BW was 629 ± 49 kg. The study was done during the autumn, with an average daytime temperature of 20°C.

Rations were formulated to mimic common TMR used for Parmigiano Reggiano cheese production, using all dry ingredients as shown previously (87.66% DM, 14.28% CP, 20.77% ADF, 23.65% starch; Cavallini et al., 2018). The basal diet was the same for all 4 treatments with or without additional long grass hay (8.8% CP, 42.6% ADF), which was the same as that used in the TMR but not part of the formulated diet. The TMR was finely chopped as typically fed in the region (particle size: 0.4% >19 mm, 15.2% >8

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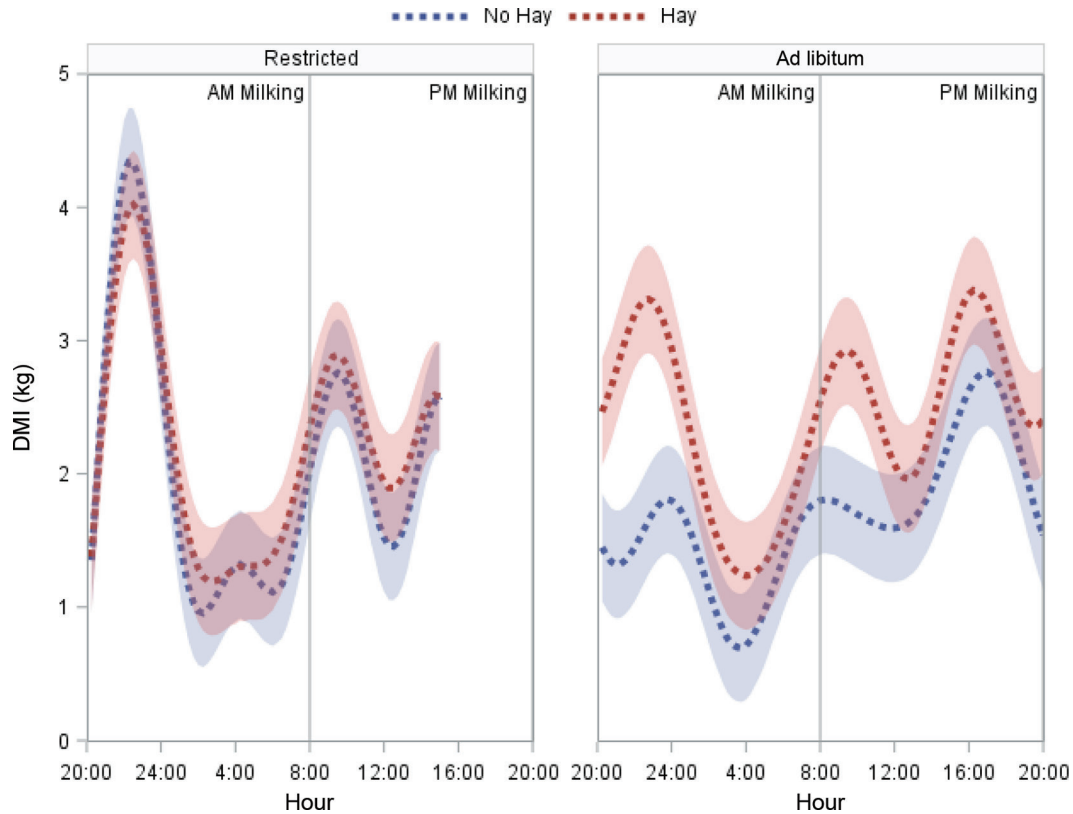


Figure 1. Dry matter intake of lactating dairy cows fed 19 or 24 h/d. Shaded areas show confidence intervals.

mm, 18.7% >4 mm, and 65.7% on the bottom pan of the Penn State Particle Separator; Lammers et al., 1996). Individual feed mangers in front of the cows were divided into 2 equal parts, one for the TMR and the other for the long grass hay. The treatments were (1) TMR offered ad libitum for 24 h, (2) TMR and hay offered ad libitum for 24 h, (3) only TMR offered for 19 h, and (4) TMR offered for 19 h and long grass hay offered ad libitum for 24 h. Cows were fed TMR for ad libitum intake (approximately $1.10 \times$ expected intake) once daily for all 4 treatments at 2000 h (Zago Mixer) and were allowed access for 24 or 19 h depending on treatment group. Cows were housed in a naturally ventilated tiestall barn and were milked 2 times daily (0800 and 1930 h) in a double-5 herringbone milking parlor. Cows were away from feed for less than 30 min per milking. For cows on limited-time TMR, diets were taken away at 1500 h (5 h before evening milking). This time period was chosen because feeds were less fresh at this period, yet it was a time during daylight hours when cows would normally be eating to some degree.

Intake was determined by recording feed offered and refused on d 15 to 21 during recording periods. Feed mangers were subdivided (for separate hay feeding when offered) on load cells to record DMI in real time. Cows were monitored for rumination activity (SCR Engineers Ltd.) from d 15 to 20. During each period, rumination time was measured using the Hi-Tag rumination monitoring system (SCR Engineers Ltd.). The data were sent to a personal computer via antenna. A software program (Data Flow, SCR Engineers Ltd.) analyzed the rumination time as minutes per

2 h with a resolution of 2 min (Schirmann et al., 2009). Rumen pH was continuously monitored by an indwelling wireless pH-transmitting unit (SmaXtec Animal Care Sales GmbH). The units measured pH every 10 min and transmitted the data in real time to a basis station using the ISM band (433 MHz). Antennas installed in the barn and milking parlor registered the sensor signals. The pH data were collected using an analog-to-digital converter and stored in an external memory chip.

Data were initially analyzed as a 4×4 Latin square design with feed available for 24 or 19 h and hay offered ad libitum or not offered. Rumination and feed intake (DMI) data were collected every 2 h. Rumen pH data were collected every 10 min, but the values were consolidated to every 2 h to stabilize the estimates and to match the collection of the rumination and DMI values.

The cosinor method (Bergendahl et al., 1996) was used in PROC MIXED (SAS version 9.02; SAS Institute Inc.), allowing for nesting of cow with repeated measures within the Latin square design. The cosinor method uses a cosine function as a model for biological rhythms (Bingham et al., 1982). Time was converted into radians, allowing the predicted values to be expressed as the sum of several cosine and sine functions. This would be similar to adding the linear, quadratic, and cubic terms to predict a nonlinear growth curve, except that polar transformations were used. The basic form of the daily rhythms was of primary interest, and this could be described by the sine and cosine functions for 24-, 12-, 8-, and 6-h cycles. No attempt was made to simplify the models by taking out insignificant cosine or sine terms. The response

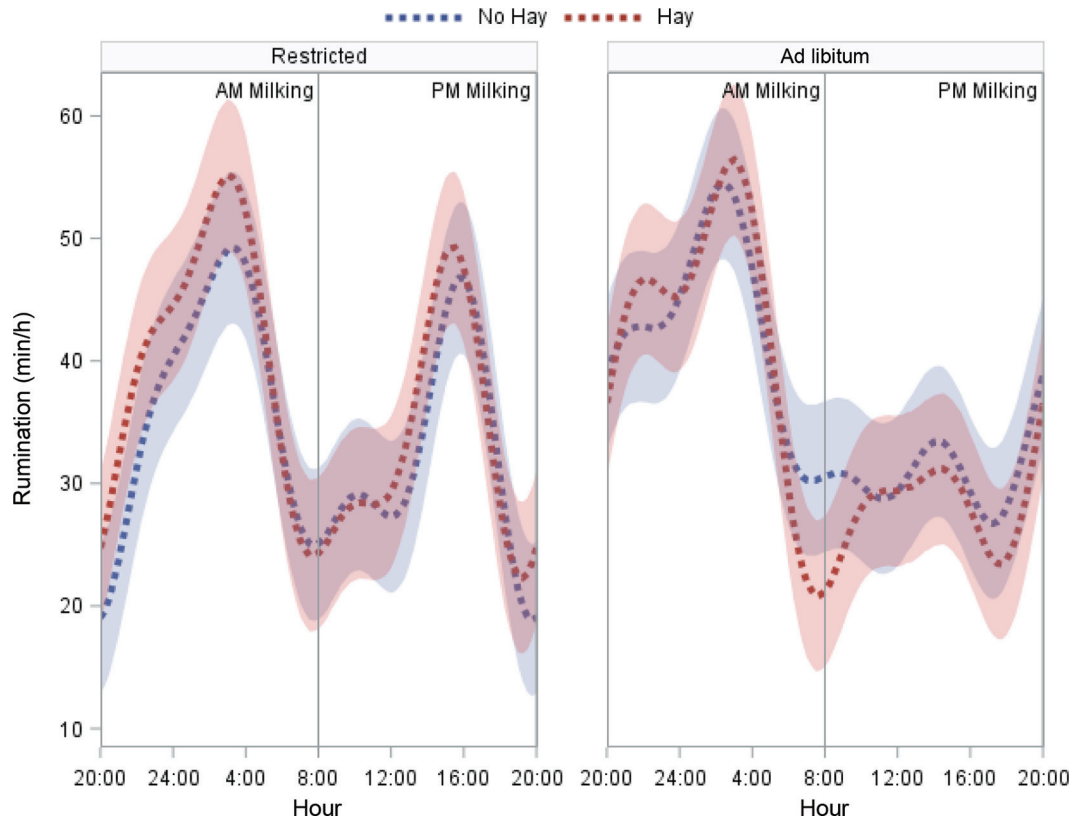


Figure 2. Rumination times of lactating dairy cows fed 19 or 24 h/d. Shaded areas show confidence intervals.

variables analyzed were DMI, rumination, and rumen pH. Data were summarized beginning at feeding (2000 h coinciding with the return from evening milking), with notation at 1500 when the remaining TMR was removed from the 19-h TMR groups for 5 h. Adjusted means were collected from the MIXED analysis to obtain the figures, and standard error was used to create confidence bands.

The nutrient intake and production components of this experiment have been reported previously (Cavallini et al., 2018). In brief, when cows were offered TMR 24 versus 19 h/d, TMR DMI increased (25.98 vs. 23.49 kg; SEM = 1.66; $P = 0.04$) and intake of supplemental hay was similar between diets. Consequently, total DMI tended to be greater for cows with 24-h TMR access (26.21 vs. 23.85 kg; SEM = 1.70; $P = 0.06$) compared with cows offered TMR for 19 h/d (Cavallini et al., 2018). When hay was offered in addition to TMR, cows consumed relatively little hay (<1 kg/d) and tended to consume more hay when TMR was offered for 19 versus 24 h/d. However, this hay intake was not equal to the reduction in TMR intake, likely due to feed palatability or preference for the TMR over the hay alone. Restricted DMI has also been shown to improve feed efficiency in lactating cows (Ben Meir et al., 2019) and may represent an alternative feeding strategy in some situations.

The combination of restricting feed in the late afternoon and offering fresh feed after the evening milking resulted in a large peak of intake at 2000 h in the restricted-fed cows with or without additional hay offered (Figure 1). These cows also had a typical second peak when they returned after the morning milking at 0800 h. Ad

libitum-fed cows fed additional hay had similar eating patterns as well as a third late-afternoon feeding time. This late-afternoon (third peak) eating could be attributable to movement around the barn due to preparation for evening milking, removing TMR from restricted cows, and general feed preparation for all animals. Cows offered ad libitum TMR with no hay had lower intake per time period after evening feeding and morning milking and followed similar eating patterns for the remainder of the day. Offering ad libitum hay as a separate feed resulted in a change in the circadian profile of DMI throughout the day other than the time during which TMR was removed. Total mixed ration DMI was lower for a given time period for both restricted groups but was not different for groups offered or not offered additional hay. After eating the small amount of hay (0.55–0.7 kg), the cows did not eat large amounts of DM after a period of 5 h of feed restriction, and total DMI only tended to be lower for TMR-restricted cows (Cavallini et al., 2018). These data were collected after the 14-d adaptation period, and the cows had modified their intake behavior, as previously shown (Maulfair et al., 2013; John et al., 2017).

The concept of evening feeding clearly shows that the pattern of eating can be spread out into 3 major eating bouts to help spread intake when feed is offered ad libitum. However, intake is affected as shown by restricting feed availability for 19 h of the day. It is common in warmer climates to feed cows in the evening rather than in the morning, thus altering the traditional feeding pattern of highest intake in the morning after fresh feed is offered (DeVries et al., 2003). It has been shown that night feeding during warmer

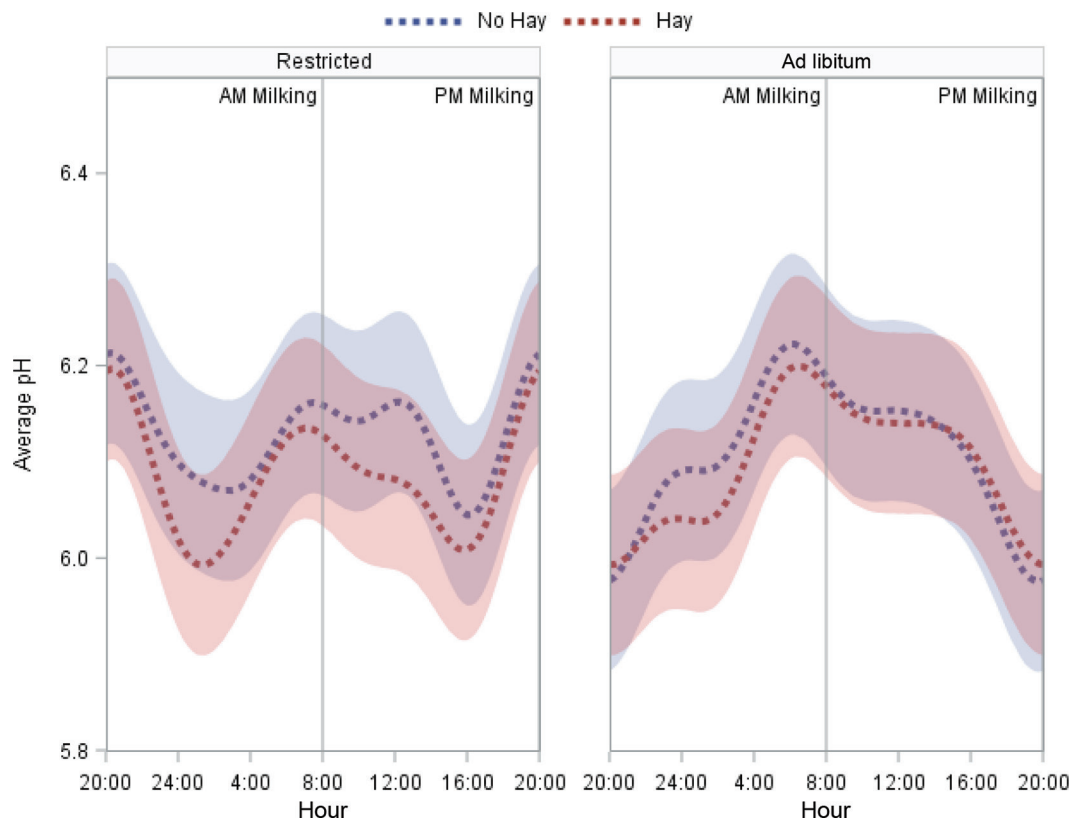


Figure 3. Rumen pH of lactating dairy cows fed 19 or 24 h/d. Shaded areas show confidence intervals.

temperatures increases intake for lactating cows for 2 h after feeding (Niu and Harvatine, 2018).

Figure 2 shows the patterns of rumination with ad libitum and restricted TMR. As anticipated, these are generally the inverse of eating times (Beauchemin et al., 1990; Sheahan et al., 2012; Salfer et al., 2018), with no marked differences in restricted or ad libitum feed availability except for the hours when feed was restricted. The TMR-restricted cows with or without hay ruminated for a large amount of time during the hours of TMR restriction. The patterns of rumination more closely mirror those in Figure 1 where hay was offered or not offered. Total daily rumination times were not different for any group (Cavallini et al., 2018). However, rumination times were higher than values considered to be the minimum threshold to ensure a normal rumen environment for a lactating dairy cow (Zebeli et al., 2007).

Overall, the rumen pH of cows was not affected by diet treatment and had a similar range of values (Cavallini et al., 2018) but different diurnal shapes due to differences in eating and rumination patterns as shown in Figure 3. Ad libitum-fed cows had a general increase in pH at night and a lower pH during the day. Restricted cows experienced a decrease in pH after eating large meals after new feed was offered and the morning milking. These cows also had an increase in pH during the time of restricted feed, when they were ruminating more than ad libitum-fed cows. Changes in pH throughout the day were also less overall in restricted-fed cows. In general, the range of pH values reflects the forages used in this study, which had lower fiber digestibility (Cavallini et al., 2018),

and hay access showed differences similar to those in a previous study (Kmicikewycz et al., 2015). However, restricted TMR intake modified the pattern of eating, ruminating, and rumen pH over the day.

Limiting TMR availability for 5 h/d changed the eating and rumination patterns of lactating dairy cows. Availability of ad libitum hay made a significant difference in DMI patterns. Rumen pH pattern throughout the day was modified in restricted-fed cows, but ranges in values were similar to those of ad libitum-fed cows. When feeding very finely chopped diets, cows adjusted to the changes in feed availability and access to long hay.

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Notes

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