Effect of converting weaned dairy calves from a component-fed diet to a total mixed ration on growth and nutrient digestibility

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ABSTRACT

The objective was to determine the effects of converting calves from a component-fed ration to a total mixed ration (TMR) at 8, 10, or 12 wk of age on intake, growth, and nutrient digestibility. Holstein calves ($n = 40$) were randomly assigned to 1 of 4 groups (no TMR, TMR conversion at 8, 10 or 12 wk; T0, T8, T10, and T12, respectively). Calves were weaned at 6 wk of age, housed individually, and studied from 7 to 14 wk of age. Rations, consisting of a 20% crude protein texturized starter and grass hay, were offered ad libitum as separate components or as a TMR with 85% starter and 15% grass hay on a dry matter (DM) basis. Intakes and body weights (BW) were measured weekly. Component intake for TMR was calculated from the proportion of grass hay and starter contained in the TMR. Fecal grab samples were collected every 9 h over 3 d for a total of 8 samples that formed a composite at 9, 11, and 13 wk of age from the same 4 calves per group. Rumen fluid samples were collected via esophageal tube at -1 , 0, 3, and 7 d relative to conversion from component to TMR. Feed and feces were evaluated for DM, neutral detergent fiber, acid detergent fiber, and acid detergent lignin (internal flow marker) to estimate digestibility. Average daily gain and final BW tended to be least for T8. Empty BW gain was significantly less for T8 than for T0 but not different from T10 or T12 ($T0 = 1.07$, $T8 = 0.93$, $T10 = 1.02$, $T12 = 1.04$ kg/d). Hip growth tended to be least for T8 and resulted in lower final hip width ($T0 = 25.9$, $T8 = 25.2$, $T10 = 25.6$, $T12 = 25.8$ cm). Intake tended to be reduced for calves converted to TMR earlier. Throughout the study, calves fed TMR ate more hay and less starter than component-fed calves. Metabolizable energy intake was less for T8 versus T0 but not different from T10 or T12 ($T0 = 8.46$, $T8 = 7.55$, $T10 = 8.01$, $T12 = 8.23$ Mcal/d). We observed no differences in feed efficiency for the dura-

tion of the study. Differences in DM digestibility were not observed, but fiber digestibility was greater for calves fed TMR at 9, 11, and 13 wk of age. Conversion to TMR increased rumen pH. These results indicate that TMR conversion increased hay consumption and subsequently decreased starter and total DM intake. This led to reduced weight and structural growth; however, calves that were converted to TMR as early as 8 wk still achieved adequate growth. The increase in rumen pH and subsequent increase in fiber digestibility allowed for calves to be converted to a 15% grass hay TMR as early as 8 wk and still achieve desirable growth goals.

Key words: feeding strategy, weaned calf, total mixed ration

INTRODUCTION

Replacement dairy heifers represent the second or third largest cost to dairy farms and, of those costs, feed accounts for the largest portion (Heinrichs et al., 2013). In an attempt to offset feed costs, heifer diets are often designed to limit expenses. As a result, heifers >6 mo of age are often fed forage-based diets (DeVries and von Keyserlingk, 2009). Heifers <6 mo of age have different rumen intake capacities and nutrient requirements and therefore require different feeding practices (NRC, 2001).

Because of changing nutrient requirements of heifers as they grow from 0 to 6 mo of age, forage feeding needs to be closely managed. There is debate surrounding forage provision for preweaning dairy calves (Suarez-Mena et al., 2016). It is well known that concentrates are the primary driver of rumen epithelial development in young calves (Stobo et al., 1966; Davis and Drackley, 1998). Hill et al. (2008) demonstrated that forage provision negatively affected intake of a texturized starter, whereas a meta-analysis by Imani et al. (2017) demonstrated that forage provision improved intake of pelleted and ground starters.

Forage provision for weaned calves is accepted and largely recommended (Heinrichs, 1996). However, there has been little to no research evaluating effects of differ-

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ent forage feeding methods for weaned calves from 2 to 4 mo of age. The 2 most common feeding methods for recently weaned calves include component feeding (forage and concentrate fed separately) and TMR feeding (Suarez-Mena et al., 2016). Unfortunately, studies do not explain why they chose to feed forage to calves in component fashion or as a TMR. As a result, questions remain about which feeding method is most beneficial and cost effective. Concerns exist about young heifers being able to consume enough energy when provided a TMR that contains either too much forage or forage of inadequate quality (Heinrichs, 1996). However, Hill et al. (2010) fed calves from 8 to 16 wk of age a TMR containing as much as 9% wheat straw, 9% chopped grass hay, or 15% long alfalfa hay and achieved ADG of 900, 1,090, and 1,070 g/d, respectively. These gains are much higher than the recommended 800 g/d for prepubertal heifers proposed by Zanton and Heinrichs (2005) to achieve maximal first-lactation milk yield. Furthermore, it has been observed that feeding TMR promotes more balanced intake of nutrients throughout the day, in addition to reducing feed bunk competition (DeVries and von Keyserlingk, 2009; Greter et al., 2010).

Recently weaned calves appear to perform well when fed a TMR, and TMR may present an opportunity to reduce feed costs through increased forage supplementation. Furthermore, provision of a TMR may encourage calves to consume increased levels of forage at an earlier age than they might otherwise if offered concentrate and forage as separate components. However, the effects of converting recently weaned calves to a TMR are still unknown. The objective of this study was to determine the effects of converting calves weaned at 6 wk from a component-fed ration to a TMR at 8, 10, or 12 wk of age on intake, growth, and nutrient digestibility. We hypothesized that at some point between 8 and 12 wk of age, calves could be converted to a TMR without negative effects on intake, growth, or nutrient digestibility.

MATERIALS AND METHODS

Animals and Treatments

All study procedures were approved by The Pennsylvania State University Institutional Animal Care and Use Committee (IACUC #47347). Forty Holstein calves (32 female; 8 male), initial BW 62.9 ± 6 kg, were randomly assigned by sex to a treatment and studied from 7 to 14 wk of age. Treatments involved converting calves from a component-fed ration to a TMR at different ages, with assignment to 1 of 4 groups: control (no TMR) and TMR conversion at 8, 10, or 12 wk (**T0**, **T8**, **T10**, and **T12**, respectively).

Calves were offered 4 L/d of a 20% CP, 20% fat medicated milk replacer (Renaissance Nutrition, Roaring Spring, PA) through 5 wk of age and 2 L/d until weaning at 6 wk of age. Texturized calf starter (East Gate Feed & Grain, Reedsville, PA) was offered free choice starting at 3 d of age. At 7 wk of age, coarsely chopped grass hay was offered alongside texturized starter as separate components, and conversion to TMR (85% texturized starter and 15% grass hay) occurred according to group assignment. The texturized starter used after 7 wk of age was the same starter used beginning on 3 d of age. Rations were offered ad libitum for the duration of the study.

The grass hay being used at the initiation of the trial was depleted with 6 wk remaining in the study. As a result, a different source of grass hay was used for the final 6 wk of the study and it differed in quality from that used for the first 12 wk (Table 1). This difference was accounted for in our statistical analyses by including week of study as a random variable. Calves used for digestibility and rumen pH data collection ($n = 16$; 4 per group) finished the trial before the depletion of our initial grass hay and, as a result, were offered consistent quality grass hay from the beginning to the end of the study. Therefore, any observed differences in digestibility or rumen pH are independent of forage quality. Nutritional analyses of feedstuffs and TMR composition are given in Table 1.

Calves were housed individually in either outside hutches ($n = 24$) or a mechanically ventilated tie-stall barn ($n = 16$) for the duration of the study. The outside hutches were bedded with sawdust as needed. Calves housed in the tie-stalls (4/group) were used for collection of digestibility and rumen pH data. Housing these individuals in the tie-stall allowed for easier and more accurate sample collection and the ability to ensure calves were not consuming bedding. Calves in the tie-stall were kept on rubber mats and bedded with sawdust only from the hips back to inhibit bedding consumption.

Sample Collection and Analysis

Body weight and hip width were measured as calves entered the trial and weekly thereafter. Calves were fed once per day at 1200 h. Feed offerings were recorded daily and refusals were collected weekly. Weekly refusals and feedstuff samples were dried in a forced-air oven at 55°C for 48 h to determine DM (AOAC International, 2000). Dried samples were ground through a Wiley mill (Arthur H. Thomas, Philadelphia, PA) using a 1-mm screen and stored for further analysis.

Fecal samples were collected from 16 calves (4/group) via rectal palpation every 9 h over 3 d for a total of 8

samples at 9, 11, and 13 wk of age. Fecal collections started 3 h after feeding and the same animals were used at each age. Fecal samples were composited using an equal weight from each and dried in a forced-air oven at 55°C for 72 h (AOAC International, 2000). After drying, fecal samples were ground through a Wiley mill (Arthur H. Thomas) using a 1-mm screen and stored for further analysis.

Dried and ground feedstuffs, refusals, and fecal samples were analyzed for DM, NDF (Van Soest et al., 1991), and ADF sequentially using an Ankom²⁰⁰ fiber analyzer (Ankom Technology Corp., Fairport, NY), with heat-stable α -amylase and sodium sulfite used in the NDF procedure. Starch was evaluated using a modified method of Hall (2009). Acid detergent lignin was determined after ADF analysis (Van Soest, 1963) and used as an internal marker to estimate digestibility. Feedstuffs were further analyzed by Cumberland Valley

Analytical Services Inc. (Waynesboro, PA) for CP, ash, Ca, P, and TDN. Then, TDN was used to estimate ME according to the NRC (2001) equation: $ME = 1.01 \times (0.04409 \times TDN) - 0.45$.

Rumen fluid samples were collected from the same animals that were used for the digestibility portion of the study. The objective was to determine changes in rumen pH around the time of conversion from a component-fed ration to a TMR. As a result, rumen fluid samples were collected from T8, T10, and T12 at 3 h post-feeding on -1, 0, 3, and 7 d relative to conversion to TMR. Samples were also collected from calves in T0, but because they did not undergo conversion to a TMR, their samples were only collected 3 h post-feeding at 8, 10, and 12 wk of age. There were some incomplete sample sets for reasons beyond our control. Group T8 had only 2 samples from d -1 and 0 and only 3 samples from d 3 post-switch, whereas T0 had only 3 samples at 8 wk of age. Furthermore, 1 sample for T0 at 12 wk could not be obtained. Samples were taken via esophageal tube. A metal suction strainer (Precision Machine Company, Lincoln, NE) attached to a pliable plastic hose with a 0.635-cm inside diameter was gently guided down the esophagus and into the rumen. A 60-mL syringe was attached to the other end of the hose and used to draw the rumen fluid sample. The first 60 mL was discarded to minimize salivary contamination. The next 50 to 100 mL of fluid was saved and immediately tested for pH using a handheld portable pH meter (model M90, Corning Inc., Corning, NY).

Calves were monitored for health and scored daily according to CalfTrack system outlined by Lesmeister and Heinrichs (2004). Fecal scores of 1 through 5 (1 = firm to soft; 5 = watery, mucus, bloody) were assigned daily by trained personnel. Days with fecal scores ≥ 2 were used to evaluate differences between groups.

Statistical Analysis

All statistical analyses were conducted in SAS (version 9.4, SAS Institute Inc., Cary, NC) using the MIXED procedure. Calf, blocked by sex, was considered the experimental unit because calves were housed individually for the entirety of the study, and all measurements were taken and known for each individual calf. Different housing was tested but ultimately not accounted for in the final model because calves accomplished the same ADG regardless of housing (1.16 ± 0.1 kg vs. 1.13 ± 0.1 kg; tiestall vs. outside hutch). Initial BW and hip width were measured at 7 wk of age (62.9 ± 6 kg and 19.9 ± 0.9 cm). Initial BW was used as a covariate in the analysis of final BW, intake, ADG, empty BW gain (EBWG), and efficiency; initial hip width was used as a covariate for final hip width and hip growth.

Table 1. Chemical and ingredient composition of feedstuffs¹

Item	Texturized starter	Grass hay ²	Grass hay ³
Nutrient composition (% of DM)			
DM	89.3	90.1	88.5
CP	23.5	13.7	8.4
ADF	8.7	37.0	41.8
NDF	20.3	57.1	65.3
Starch	27.6	1.3	1.5
Crude fat ⁴	3.6	2.8	2.8
Ash	7.5	8.1	6.1
Ca	1.07	0.80	0.34
P	0.73	0.37	0.26
ME ⁵ (Mcal/kg)	3.0	2.3	2.0
Ingredient (% as fed)			
Roasted flaked corn	18.6		
Whole oats	2.5		
20% calf pellet	72.1		
Liquid molasses	6.3		
Soybean oil	0.5		
Calf flavor	0.1		
Rumensin ⁶	0.03		

¹The TMR contained 15% grass hay and 85% texturized starter on a DM basis. Composition of TMR for first 12 wk: 89.4% DM, 22.0% CP, 12.9% ADF, 25.8% NDF, 23.7% starch, 7.6% ash, 1.03% Ca, 0.68% P, and 2.9 Mcal/kg. Composition of TMR for final 6 wk: 89.2% DM, 21.2% CP, 13.7% ADF, 27.1% NDF, 23.6% starch, 7.3% ash, 0.96% Ca, 0.66% P, and 2.9 Mcal/kg.

²Chemical composition of grass hay used during the first 12 wk of the study. Calves used for the digestibility portion of the study consumed this grass hay.

³Chemical composition of grass hay used for the final 6 wk of the study.

⁴Crude fat of texturized starter is tag value. Crude fat of grass hay is average (SD 0.48) obtained from DairyOne Feed Comp Library for Pennsylvania (<https://dairyyone.com/services/forage-laboratory-services/feed-composition-library/interactive-feed-composition-libraries/>) in June 2016.

⁵Estimated according to NRC (2001) equation: $ME = 1.01 \times (0.04409 \times TDN) - 0.45$.

⁶Elanco, Greenfield, IN.

Initial and final weight and hip measurements were evaluated with the fixed effect of treatment, the random block effect of sex, and covariates where necessary. Fecal days ≥ 2 were evaluated with the same fixed and random effects as initial and final weight and hip measurements. Intake and growth variables evaluated over time used an expanded model, which added age as a fixed repeated effect, the interaction between group and age, and random effects of calf and week of study. The random effect of week of study was included to account for forage quality differences throughout the study. Bayesian information criterion (BIC) was used to evaluate the inclusion of the random effect of week of study or forage quality within the model; week of study resulted in a lower BIC and was therefore chosen. An autoregressive [AR(1)] covariance matrix was applied as determined by Akaike's information criterion (AIC).

The random block effects of sex and week of study were removed from the analysis of digestibility and rumen pH because only heifers were used and they were offered the same quality forage for the duration of the study. Digestibility and rumen pH were evaluated with the fixed effect of treatment, repeated effect of age, interaction between group and age, and random effect of calf. A variance component covariance matrix was used for digestibility, as determined by AIC, while SP(POW) (spatial power) was used for rumen pH due to unevenly spaced sampling intervals.

The slice option within SAS was used for all variables determined using repeated measures to elucidate effects of diet and age. Degrees of freedom for all procedures were determined using the Kenward-Roger approximation. All means are reported as least squares means with the standard error and compared with the Tukey adjustment. Significant differences were declared when $P \leq 0.05$ and tendency when $0.05 < P \leq 0.10$.

RESULTS AND DISCUSSION

Diets

The nutrient compositions of feedstuffs and TMR are presented in Table 1. Calves were offered texturized starter and coarsely chopped grass hay for the duration of the study in component fashion or as a TMR according to assigned treatment. Grass hay fed through the first 12 wk of the study differed from what was fed in the final 6 wk in ADF and NDF by 4.8 and 8.2% on a DM basis, respectively. Although these are substantial differences, the effects on ADF (12.9 vs. 13.7%) and NDF (25.8 vs. 27.1%) contents of the TMR were minimal due to the relatively low inclusion level of grass hay.

Growth and Intake

Growth and intake variables are presented in Table 2. Dry matter intake tended to be least for group T8. Furthermore, the composition of the DM consumed was different between groups, with hay intake increasing and starter intake decreasing the earlier that calves started consuming TMR. We expected that converting calves to a 15% grass hay TMR would force an increase in grass hay consumption and a subsequent decrease in starter consumption. This change can be seen in Figure 1. It is also interesting to note that grass hay intake leveled off after 11 wk for T0 at about 0.28 kg/d (8% of total DMI), while starter intake continued to increase. This indicates that when calves at this age are given the choice between grass hay and starter, they prefer starter, which may lead to overconsuming concentrate. In the current study, this appears to be the case, because the calves left on a component ration (T0) achieved higher than necessary ADG, which may increase body condition. If calves are exceeding desirable growth rates by overconsumption of concentrate, there is potential for cost savings by offering a TMR with increased levels of grass hay. The decrease in DMI observed in animals consuming greater levels of forage aligns with others that performed similar trials with increasing forage levels (Hill et al., 2008, 2009, 2010). Interestingly, despite differences in dietary NDF (% DM basis) between TMR and component feeding, NDF intake did not vary between groups for the duration of the study. Figure 1d shows NDF intake on a weekly basis; no differences were observed until after 12 wk and the difference did not appear to be directly related to ration composition until 14 wk. At 12 wk, T10 consumed more NDF than component-fed groups T0 and T12 ($P < 0.05$) as well as TMR group T8 ($P = 0.06$). At 13 wk, the component-fed group T0 consumed less NDF than T10 and T12 ($P < 0.05$) but did not consume a different amount from T8 ($P = 0.43$). At 14 wk, all of the TMR-fed groups consumed more NDF than T0, as calves in T8 finally started to separate from those in T0 ($P = 0.09$). Until the animals reached 14 wk of age, calves in T0 were able to consume similar levels of NDF by consuming greater quantities of starter. It is well known that NDF influences DMI in cows (Van Soest, 1965) and growing heifers (Tomlinson et al., 1991). However, Tomlinson et al. (1991) were studying heifers that were older than animals in the current study. Animals from 7 to 14 wk of age in the present study did not appear to have the same ability to consume NDF as older animals (Hoffman et al., 2008). Hoffman et al. (2008) showed that NDF intake as a percent of BW was near 1% for Holstein heifers from ~4 mo of

age to calving. In the current study, NDF intake as a percent of BW increased with age, but was only 0.88% for the TMR groups at the conclusion of the study. The fact that animals in the current study consumed similar levels of NDF but showed a tendency for reduced intake as forage consumption increased suggests that, within this age range, the way the NDF is supplied (forage vs. nonforage fiber sources) may play a greater role in intake regulation than simply the amount of NDF consumed. The differing composition in DM consumed did, however, lead to a difference in ME intake, with T8 consuming the least and T0 consuming the greatest amount of ME (Mcal/d). Dry matter and ME intake leveled off as expected from 8 to 9 wk and from 10 to 11 wk for T8 and T10, respectively, but T12 did not show the same trend as DM, and ME intake continued to increase from 12 to 13 wk. Animals converted to TMR at 12 wk would be larger, and their increased body capacity would likely allow them to overcome the change in nutrient consumption. We found no differences between groups in DMI as a percent of BW or feed efficiency, although both were affected by age. Dry matter intake as a percent of BW increased with age, whereas feed efficiency decreased from 8 to 10 wk of age before leveling off for the remainder of the study.

Calves in group T8 tended to have the lowest final BW. A tendency for lower final BW is in agreement

with the tendency for reduced ADG in group T8. Furthermore, T8 had 13% lower EBWG than T0, whereas EBWG in T10 and T12 did not differ significantly from either. We observed an approximate 100 g/d increase in ADG and EBWG when calves were converted to a 15% grass hay TMR at 10 wk instead of 8 wk. This could indicate that older calves require less time to adapt to rations containing increased levels of forage. This is logical, considering that older calves also have increased rumen capacity. Weekly ADG showed that T10 and T12 had slightly increased ADG in the week after they were converted to TMR, whereas ADG in the T8 group decreased in the week after TMR conversion and stayed suppressed for an additional week before rebounding at wk 11. This suggests that T8 calves required additional time to adapt to the increased level of forage offered. From 11 wk to the end of the study, we detected no differences in ADG between groups. Waiting to offer TMR until 10 or 12 wk resulted in ADG and EBWG being much closer to that of calves in the T0 group. Calves switching at 8 wk may not have the rumen capacity to consume a 15% grass hay TMR without decreasing their intake and subsequent growth rate for 1 to 2 wk (Heinrichs, 1996). Despite the tendency for reduced ADG observed for group T8, an ADG of 1 kg/d for this age group is more than sufficient to meet weight goals for breeding and calving. Calves in this

Table 2. Growth and feed intake of weaned dairy calves offered starter and grass hay in component fashion and converted to a TMR at various ages or not at all

Item	Treatment (Trt) ¹				SE	Contrast, <i>P</i> -value		
	T0	T8	T10	T12		Trt	Age	Trt × Age
Growth								
Initial BW ² (kg)	67.4 ^a	61.6 ^{ab}	60.6 ^b	61.9 ^{ab}	1.65	0.026	—	—
Final BW (kg)	120.1	114.3	119.4	120.6	2.55	0.087	—	—
ADG (kg/d)	1.16	1.04	1.14	1.16	0.10	0.089	<0.001	0.901
EBWG ³ (kg/d)	1.07 ^a	0.93 ^b	1.02 ^{ab}	1.04 ^{ab}	0.09	0.045	<0.001	0.268
Initial hip width ² (cm)	20.6 ^a	19.7 ^{ab}	19.6 ^b	19.7 ^{ab}	0.25	0.029	—	—
Final hip width (cm)	25.9 ^a	25.2 ^b	25.6 ^{ab}	25.8 ^{ab}	0.21	0.031	—	—
Hip growth (cm/wk)	0.84	0.76	0.81	0.83	0.08	0.096	0.140	0.624
Intake (kg/d unless noted otherwise)								
DM	3.08	2.79	2.95	3.01	0.11	0.071	<0.001	0.531
Grass hay	0.23 ^c	0.39 ^a	0.34 ^{ba}	0.27 ^{bc}	0.03	<0.001	<0.001	<0.001
Starter	2.85 ^a	2.40 ^b	2.60 ^{ab}	2.73 ^a	0.11	<0.001	<0.001	<0.001
DMI (% of BW)	3.21	3.04	3.09	3.15	0.09	0.293	<0.001	0.511
NDF	0.72	0.75	0.76	0.74	0.03	0.683	<0.001	<0.001
NDF (% of BW)	0.75	0.81	0.79	0.76	0.03	0.119	<0.001	<0.001
ME ⁴ (Mcal/d)	8.56 ^a	7.70 ^b	8.14 ^{ab}	8.35 ^{ab}	0.29	0.019	<0.001	0.117
Feed efficiency ⁵ (kg/kg)	0.39	0.38	0.41	0.40	0.03	0.425	<0.001	0.739

^{a-c}Means within a row with different superscripts differ at $P \leq 0.05$.

¹T0 = component-fed for duration of study; T8, T10, and T12 were converted to TMR at 8, 10 and 12 wk of age, respectively.

²Initial BW and hip width at 7 wk of age.

³Empty BW gain; calculated according to equations given by Jahn and Chandler (1976).

⁴ME intake was calculated by multiplying ME (Mcal/kg) content of grass hay and starter by the DM (kg) consumed of each.

⁵Feed efficiency was calculated by dividing ADG by DMI.

study (62.9 kg at 7 wk of age) could have gained as little as 900 g/d ADG from 2 to 4 mo, 850 g/d ADG during the prepubertal phase (4 to 10 mo; Zanton and Heinrichs, 2005), and 1 kg/d from 10 mo to calving and still accomplish recommended growth goals of 55% mature BW at breeding (13 mo) and 85% mature BW at calving (22 mo; mature BW at Penn State dairy is 680 kg). The ADG of T8 was comparable to that of other studies feeding calves of similar age a TMR with 15% grass (0.981 kg/d; Hill et al., 2009) and 15% alfalfa hay (1.07 kg/d; Hill et al., 2010). However, Hill et al. (2008) fed similar aged calves a 15% grass hay TMR and found a lower ADG (0.90 kg/d) than observed in the present study. This difference is likely due to differing energy

densities of the diets offered by Hill et al. (2008) and the present study (estimated ME = 2.46 vs. 2.7 Mcal/kg, respectively).

Final hip width of T8 calves was less than that of T0, whereas hip width in T10 and T12 calves did not differ from either T0 or T8. The difference in final hip width was a result of a tendency in T8 calves for reduced weekly hip growth. Weekly hip growth in this study was aligned with that observed by Hill et al. (2009). In addition, each group in this study was on track to exceed the hip width observed by Zanton and Heinrichs (2007) for calves that were 117 ± 2 d of age. Although a difference in final hip width existed between T8 and T0, animals in this study grew at rates comparable to

Figure 1. Weekly intakes of weaned calves fed a component-based ration (no TMR; T0) or converted to a TMR at 8, 10, or 12 wk (T8, T10, and T12, respectively). (A) Weekly DMI of weaned dairy calves. Asterisks (*) indicate differences ($P \leq 0.05$) between groups at that age (10 wk: T8 < T12; 11 wk: T8 < T0 and T12; 12 wk: T8 < T0 and T12; 13 wk: T8 < T0; 14 wk: T8 < T0). Daggers (†) indicate trends ($0.05 \leq P \leq 0.1$) between groups at that age (10 wk: T8 < T12; 11 wk: T10 < T12; 12 wk: T8 < T10; 14 wk: T12 < T0). (B) Weekly texturized starter intake of weaned dairy calves. Asterisks indicate differences ($P \leq 0.05$) between groups at that age (9 and 10 wk: T8 < T0, T10, and T12; 11 and 12 wk: T8 and T10 < T0 and T12; 13 and 14 wk: T8, T10, and T12 < T0). Daggers indicate trends ($0.05 \leq P \leq 0.1$) between groups at that age (12 wk: T8 < T10). (C) Weekly grass hay intake of weaned dairy calves. Asterisks indicate differences ($P \leq 0.05$) between groups at that age (9 and 10 wk: T8 > T0, T10, and T12; 11 and 12 wk: T8 and T10 > T0 and T12; 13 and 14 wk: T8, T10, and T12 > T0). (D) Weekly NDF intake for weaned dairy calves. Asterisks indicate differences ($P \leq 0.05$) between groups at that age (12 wk: T10 > T0 and T12; 13 wk: T10 and T12 > T0; 14 wk: T10 and T12 > T0). Daggers indicate trends ($0.05 \leq P \leq 0.1$) between groups at that age (9 wk: T8 > T10 and T12; 11 wk: T10 > T12; 12 wk: T10 > T8; 14 wk: T8 > T0). Error bars represent $\pm$ SE.

calves in other studies and would meet frame growth goals. It is also important to note that calves in this study were housed individually, and intake and growth may have been affected differently if they had been group housed.

Health

Fecal scores were assigned to calves daily, and number of days with fecal score ≥ 2 was evaluated to determine whether differences existed between the groups. These data are not reported because days with fecal score ≥ 2 did not differ between groups (T0 = 5.5, T8 = 5.9, T10 = 1.7, T12 = 4.4; $P = 0.2$). Furthermore, as can be inferred from the low number of days with fecal score ≥ 2 , calves in this study were quite healthy.

Digestibility

Apparent nutrient digestibility is presented in Table 3. Digestibility measurements were estimated from samples taken at 9, 11, and 13 wk of age using ADL as an internal marker. We chose ADL as a digestibility marker after sample collection because of the insufficient quantities of dried feces needed to run the acid-insoluble ash procedure in duplicate. The use of ADL in predicting digestibility has been shown to be more suitable for diets containing grass hay than for diets containing silage (Huhtanen et al., 1994). The most significant sources of error associated with the use of ADL as a marker include incomplete recovery and consumption of diets differing in ADL (% DM basis; Van Soest, 1982). The recovery of ADL may have been insufficient, which led to an underestimation of DM, NDF, and ADF digestibility in the present study. The digestibility values reported in this study are low compared with those of calves at 12 and 16 wk of age using acid-insoluble ash as an internal marker (Hill et al., 2016; Dennis et al., 2018) or of calves at 9 wk of age using total fecal collection (Castells et al., 2012). However, DM and NDF digestibility values of TMR-fed calves in the present study are similar to values reported by Gelsinger et al. (2019) for calves consuming a texturized starter from 11 to 15 wk of age (DM and NDF digestibility = 71.1 and 31.3%, respectively) and Hill et al. (2016) for calves at 11 wk of age (DM, NDF, and ADF digestibility = 72.2, 32.1, and 21.0%, respectively). Gelsinger et al. (2019) also reported digestibility values at 5, 7, and 9 wk of age that were greater than those at 11, 13, and 15 wk of age, indicating a change in digestibility as calves aged. Based on these comparisons, it is difficult to say definitively whether the values reported here are inaccurate, despite them seeming low. An advantage of the current study is that calves consuming either the

TMR or the component-fed ration consumed similar amounts of ADL (2.9 vs. 2.8% on a DM basis, respectively). Therefore, although the values themselves may err on the low side, the similar consumption of ADL allows reasonable comparisons to be made between the groups at various ages, with confidence that the observed differences in digestibility were real and can be attributed to the way the diet was offered (TMR vs. separate components). For further validation, feedstuffs and pooled fecal samples for each group at 11 wk of age were analyzed for undigestible NDF after 240 h in vitro incubation (uNDF240; Cumberland Valley Analytical Services). We chose 11 wk of age for this check because an even number of groups were being component-fed versus TMR at this time point. Digestibility estimations from uNDF240 confirmed that fiber digestibility was higher for calves on TMR than for those fed in component fashion.

The only observed differences in DM digestibility were at 9 wk when T0 exhibited the least and T12 exhibited the greatest; T8 and T10 did not differ from either group. The reason for this difference is not readily apparent, as T0 and T12 were both consuming a component-fed ration at 9 wk. Digestibility of NDF and ADF changed in a similar manner when calves were converted from component feeding to a TMR. Calves consuming a TMR had significantly increased NDF and ADF digestibility at every age that digestibility was measured. Interestingly, this difference in fiber digestibility is not attributable to differences in NDF intake, as has been observed by others (Dennis et al., 2018). Groups in this study consumed the same amount of NDF at 9 and 11 wk of age. At 13 wk of age, T0 calves consumed less NDF than T10 and T12; however, T0 consumed the same amount of NDF as T8 that week, but differences in NDF and ADF digestibility between T0 and T8 were observed at 13 wk. Although NDF consumption was similar between groups, the form in which it was ingested did vary. Calves consuming TMR were getting greater amounts of NDF from grass hay, whereas component-fed calves were receiving greater amounts of NDF from nonforage fiber sources (NFFS) contained within the pellet of the texturized starter. These results may suggest that NFFS do not provide as digestible a form of NDF as grass hay or that increased inclusion of grass hay is necessary to maximize the potential NDF digestibility of NFFS. Because of the low forage intake of component-fed calves and small particle size of NFFS, it is likely that component-fed calves experienced greater rates of passage (Nakamura and Owen, 1989) that ended up causing reduced NDF and ADF digestibility (Grant, 1997). This explanation also aligns with low digestibility observed by Gelsinger et al. (2019) in which calves consumed all of their NDF

from NFFS contained within pellets. The interactions between forage and NFFS need to be investigated for calves from 2 to 4 mo of age as they often consume diets low in forage and high in NFFS and may not be digesting these diets at an optimal level.

Significant effects of age on NDF and ADF digestibility were observed when calves were converted to a TMR and experienced increased digestibility. However, it is interesting to note that, although not significant, values consistently decreased with age when calves were consuming their diet in a consistent fashion: T0 and T8 had reduced digestibility of NDF and ADF from 9 to 13 wk, T10 had reduced digestibility from 11 to 13 wk, and T12 had reduced digestibility from 9 to 11 wk. Gelsinger et al. (2019) observed similar results as digestibility decreased linearly from 5 to 15 wk of age. This could be a result of increased passage rate caused by increased intake (Pino et al., 2018). A similar age effect was observed for starch digestibility, except all groups were equally affected and the decrease was not biologically significant.

Rumen pH

Rumen pH and how it changed relative to day of diet conversion is shown in Figure 2. We observed no significant differences between the groups, with T8 exhibiting the lowest pH and T12 exhibiting the highest pH. This could be an indication of an age effect, where rumen pH increases with age as a result of increased absorptive capacity of the rumen epithelium (Baldwin et al., 2004) or increased saliva production as the calves aged (Kay,

1960). However, age is also confounded by increases in grass hay intake, which may have been responsible for the increase in pH seen between calves as they got older. All groups in this study consumed the same amount of grass hay at 8 wk. However, T10 and T12 calves increased grass hay intake from 8 to 10 wk and from 8 to 12 wk, respectively. Therefore, in the current study, it was impossible to distinguish whether differences between groups were a result of age or increased grass hay intake. Studies have shown decreases in pH as calves aged from 2 to 8 wk (Beharka et al., 1998; Lesmeister and Heinrichs, 2004; Suarez-Mena et al., 2015). However, it should be noted that those results are for younger calves, and Beharka et al. (1998) also showed an increase in pH from 8 to 10 wk, suggesting that important physiological changes are occurring in calves between 8 and 10 wk of age that affect rumen pH. It is also apparent from the current results that converting calves to a TMR increased rumen pH. Rumen pH at d -1 and 0 relative to diet conversion was lower than that at d 3 or 7 after converting to a TMR. This is likely the result of increased forage consumption and in agreement with findings from the meta-analysis of Imani et al. (2017), which showed that forage provision increased ruminal pH in the postweaning period. Increased rumen pH provides an environment more suitable for cellulolytic bacteria growth (Russell and Wilson, 1996), which likely played a role in the increased fiber digestibility observed. Rumen pH was measured for T0 calves at 8, 10, and 12 wk (5.42, 5.75, and 5.89 respectively) and there were no differences between week ($P > 0.1$).

Table 3. Nutrient digestibility of weaned dairy calves at 9, 11, or 13 wk of age consuming starter and grass hay in component fashion or as a TMR

Digestibility (%) and age (wk)	Group ¹				SE	Contrast, <i>P</i> -value		
	T0	T8	T10	T12		Group	Age	Group × Age
DM								
9	66.67 ^b	71.18 ^{ab}	69.14 ^{ab}	71.78 ^a	1.65	0.146	0.828	0.888
11	67.37	69.91	69.50	69.39				
13	68.44	68.99	68.70	70.27				
NDF								
9	25.06 ^{bc}	43.59 ^a	22.83 ^{c,x}	30.06 ^{b,x}	2.37	<0.001	0.017	<0.001
11	27.27 ^b	41.70 ^a	40.93 ^{a,y}	29.13 ^{b,x}				
13	23.87 ^b	38.10 ^a	38.05 ^{a,y}	39.96 ^{a,y}				
ADF								
9	14.13 ^b	33.72 ^{a,x}	13.14 ^{b,x}	18.44 ^{b,x}	2.18	<0.001	0.115	<0.001
11	16.22 ^b	27.64 ^{a,y}	29.05 ^{a,y}	15.20 ^{b,x}				
13	11.18 ^b	25.79 ^{a,y}	27.02 ^{a,y}	27.84 ^{a,y}				
Starch								
9	98.97	99.31	98.84	99.16	0.39	0.576	0.030	0.852
11	98.69	99.14	99.50	99.41				
13	98.17	98.81	98.57	98.48				

^{a-c}Means within a row with different superscripts differ at $P \leq 0.05$.

^{x,y}Means within a column and digestibility variable with different superscripts differ at $P \leq 0.05$.

¹T0 = component-fed for duration of study; T8, T10, and T12 were converted to TMR at 8, 10 and 12 wk of age, respectively.

Figure 2. Effects of group and day of diet conversion on rumen pH. (A) Rumen pH of weaned dairy calves converted from a component-fed ration to a TMR at 8, 10, or 12 wk of age (T8, T10, and T12, respectively); (B) rumen pH of weaned dairy calves relative to day of diet conversion. Interaction effects between group and day were not significant ($P > 0.1$). Different letters indicate significant differences between group (A) or days relative to diet conversion (B).

CONCLUSIONS

Calves converted to TMR at 8 wk had reduced EBWG but only a tendency for reduced ADG. They also finished the study with the smallest final hip width. The differences in growth can be attributed to a tendency for reduced DMI and significantly reduced ME intake. Conversion to TMR results in increased grass hay and decreased textured starter consumption. Converting calves to TMR increased rumen pH and NDF and ADF digestibility. The increases in fiber digestibility allowed calves consuming TMR to reduce grain intake while maintaining competitive growth rates. As a result of maintained growth and differences in composition of DM consumed, TMR may represent an effective tool for reducing feeding expenses for calves aged 2 to 4 mo being fed ad libitum. Based on these results, we conclude that calves may be converted to a 15% grass hay TMR and achieve desirable levels of intake and growth through improvements in fiber digestibility.

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