Utilization of roughages and concentrates relative to that of milk replacer increases strongly with age in veal calves

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ABSTRACT

We aimed to investigate the feeding values of milk replacer (MR), roughage, and concentrates for veal calves in a paired-gain setting, thus avoiding any prior assumptions in feeding values and major differences in nutrient intakes. One hundred sixty male Holstein-Friesian calves at 2 wk of age and 45 ± 0.2 kg of body weight (BW) were included in the experiment. Calves were allocated to pens (5 calves per pen) and pens were randomly assigned to 1 of 4 solid feed (SF) levels: SF1, SF2, SF3, or SF4, respectively, and to 1 of 2 roughage-to-concentrate (R:C) ratios: 20:80 or 50:50. An adaptation period from wk 1 to 10 preceded the experimental period (wk 11 to 27). Total dry matter (DM) intake from SF was targeted to reach 20, 100, 180, and 260 kg of DM for SF1 to SF4, respectively, during the 16-wk experimental period, and increased with preplanned, equal weekly increments. Roughage was composed of 50% corn silage and 50% chopped wheat straw based on DM. The quantity of MR provided was adjusted every 2 wk based on BW to achieve similar targeted rates of carcass gain across treatments. The reduction in MR provided (in kg of DM) to realize equal rates of carcass gain with inclusion of SF (in kg of DM) differed between the R:C ratio of 50:50 (0.41 kg of MR/kg of SF) and the R:C ratio of 20:80 (0.52 kg of MR/kg of SF). As carcass gain unintentionally increased with SF intake, the paired-gain objective was not fully achieved. When adjusted for realized rates of carcass gain, calves fed an R:C ratio of 20:80 still required 10% less MR than calves fed an R:C ratio of 50:50 for equal rates of carcass gain, indicating that the utilization of SF for gain increased with concentrate inclusion. Averaged for the 16-wk experimental period, the feeding value of

MR relative to that of concentrates and roughages was close to that predicted based on their respective digestible energy contents. Nevertheless, the feeding value of SF relative to that of MR increased substantially with age. Therefore, additivity in feeding values of these ration components cannot be assumed. The results of the current study may contribute to the development of new concepts for formulation of veal calf diets with substantial amounts of SF.

Key words: veal calf, growth performance, nutrient utilization, forage

INTRODUCTION

Provision of a minimum daily amount (50 to 250 g) of fibrous feed for veal calves is compulsory according to guidelines of the European Union. Solid feed (SF) provision reduces nonnutritive oral behaviors (Kooijman et al., 1991; Veissier et al., 1998; Webb et al., 2012), thereby contributing to improved calf welfare. In addition, the increasing cost of milk replacer (MR) ingredients provides an economic incentive to replace MR with SF.

When combining SF and MR, interactions occurring at the level of digestion or postabsorption may influence nutrient utilization and growth performance in veal calves. Milk-fed calves provided with concentrate feed as the only SF source had signs of parakeratosis and so-called plaque formation (i.e., patches of focal mucosa inflammation with coalescing and adhering papillae covered by SF particles, hair, and cell debris), which may inhibit rumen development and nutrient uptake (Suárez et al., 2006, 2007). Early rumen development is thought to increase utilization of SF in veal calves, especially toward the end of the fattening period (Berends et al., 2012b). However, the provision of SF to veal calves may increase the prevalence of abomasal lesions (Welchman and Baust, 1987; Mattiello et al., 2002; Brscic et al., 2011) and concentrate provision has been associated with ruminal drinking; that is, leakage

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of MR into the rumen (Berends et al., 2012b). Recently, it has been shown that urea recycling contributes to nitrogen retention in milk-fed calves provided with a low-protein SF (Berends et al., 2012a) but this contribution decreases with increasing protein content in the SF (H. Berends, unpublished data).

Such interactions between MR and SF complicate an accurate prediction of the feeding value of a ration consisting of MR and SF in veal calves when based on well-documented separate effects of SF only (e.g., Ortigues et al., 1990) and MR only (e.g., Gerrits et al., 1996). Studying the effect of substantial exchanges of MR for SF raises methodological problems. The incremental feeding value of a particular mixture of SF is typically evaluated using a dose-response approach. When MR intake is fixed and an incremental dose of SF is provided (see e.g., Berends et al., 2012a), the assumption that differences in BW gain do not influence the feeding value of the SF provided may be violated. Furthermore, SF intake will likely affect the carcass weight:live weight ratio, which needs to be considered when comparing feeding strategies. When MR is exchanged for SF on a digestible energy (DE) basis (see e.g., Labussiere et al., 2009a), assumptions have to be made with regard to the DE content of all dietary ingredients before the start of the experiment. With increasing quantities of MR being replaced by SF, these design problems are exacerbated. To circumvent these methodological issues, the current study assessed the feeding values of MR, concentrates, and roughages for veal calves in a paired-gain setup. Therefore, groups of calves were subjected to preset levels of concentrate and roughage intake, whereas the level of MR was adjusted to target equal rates of carcass gain across treatments. In this way, a substantial interchange of MR, concentrates, and roughages can be addressed while avoiding undesirable changes in the rate of BW gain. Differences in feeding values between these main ration components are addressed within the bounds of a particular choice of roughage and composition of concentrates or MR.

MATERIALS AND METHODS

This study was conducted at the research facilities of VanDrie Group (Scherpenzeel, the Netherlands). Procedures complied with the Dutch Law on Experimental Animals and the ETS123 (Council of Europe 1985 and the 86/609/EEC Directive) and were approved by the Animal Care and Use Committee of Wageningen University (Wageningen, the Netherlands).

Animals, Experimental Design, and Housing

One hundred sixty male Holstein-Friesian calves were purchased from commercial dairy farms at 2 wk of age, selected based on BW, uniformity, and clinical health. Mean BW upon arrival was 45 ± 0.2 kg. Calves were randomly allocated to pens (5 calves per pen). We used a 2×4 factorial arrangement of treatments in a completely randomized experiment with 4 pens per treatment combination and pen as the experimental unit. We had 2 levels of roughage-to-concentrate (R:C) ratio, 20:80 or 50:50 on a DM basis, and 4 levels of SF: SF1, SF2, SF3, or SF4, respectively (Table 1). The experiment consisted of 2 successive periods—an adaptation period from wk 1 to 10 and an experimental period from wk 11 to 27. During the adaptation period, all pens were exposed to their assigned SF level but an R:C ratio of 50:50 was used to allow for optimal rumen development as assessed in earlier studies (Berends et al., 2012b, Suárez et al., 2007). At the onset of the experimental period (i.e., at wk 11), pens were exposed to their assigned SF level and their assigned R:C ratio. Animal health was checked daily. Hemoglobin concentration in blood was monitored throughout the trial, at wk 3, 7, 11, 15, 19, 23, and at slaughter, and corrected to comply with the minimum EU level of 4.5 mmol/L at the end of the fattening period.

Pens measured 3×3 m and were equipped with open fences and wooden-slatted floors, without bedding material. During the first 4 wk, calves were kept individually in 0.9-m^2 temporary pens placed inside the

Table 1. Experimental design and number of pens per treatment

Solid feed (SF) level	Target DMI ¹	No. of pens/treatment ²	
		R:C 20:80	R:C 50:50
SF1	20	4	4
SF2	100	4	4
SF3	180	4	4
SF4	260	4	4

¹Cumulative DMI from solid feed (kg of DM) during the 17-wk experimental period.

²R:C = roughage-to-concentrate ratio on a DM basis. Roughage consisted of 50% corn silage and 50% chopped wheat straw on a DM basis.

group pen to facilitate monitoring of individual feeding behavior and health. Calves were exposed to daylight and artificial light from 0500 to 2300 h and exposed to darkness during the remainder of the day.

Diets and Feeding

Roughage consisted of 50% corn silage and 50% chopped wheat straw on a DM basis (see Table 2 for composition). During the first 4 wk of the adaptation period, corn silage was replaced, on a DM basis, with alfalfa hay to stimulate SF intake. The SF offered to calves increased at preplanned, equal weekly increments. Cumulative DMI from SF during the experimental period was targeted to reach 20 kg of DM for SF1, 100 kg of DM for SF2, 180 kg of DM for SF3, and 260 kg of DM for SF4. The quantity of MR was calculated to achieve similar targeted rates of carcass gain across treatments, and was adjusted every other week based on the realized BW gain in the preceding 2-wk period. Rates of carcass gain were estimated from the measured rates of BW gain. We assumed rumen tissue mass and contents to represent the most relevant difference between live weight gain and carcass weight gain (Berends et al., 2012b) and assumed these proportional to SF intake. Therefore, data from previous trials were used to predict rumen mass and content for each SF level (Suárez et al., 2007; Berends et al., 2012a).

Concentrate composition (Table 2) was designed to meet mineral and vitamin requirements for beef cattle (NRC, 2000). Milk replacer was reconstituted with water, and the concentration increased gradually from 125 to 188 g/L for all treatments simultaneously during the experiment. The MR was supplied in buckets at 40 to 41°C and provided twice daily in equally sized meals at 0600 and 1600 h. Calves were allowed 15 min

to consume the milk; MR refusals were collected and weighed. During the first 8 wk of the adaptation period, calves received a commercial starter MR based on 32% whey powder and 30% skim milk powder with 223 g of CP/kg of DM and 180 g of crude fat/kg of DM. The experimental MR (Table 3) was provided during the last 2 wk of the adaptation period and during the experimental period and it was introduced over 3 feedings. The SF was provided as a TMR in a long feed trough in front of the pen, directly after the morning meal. Feed refusals were weighed once daily. During the first 4 wk of the adaptation period, calves were allowed ad libitum access for 20 min to water supplied in buckets around noon. From wk 5 onward, calves had free access to water via drinking nipples.

Measurements

Feed Intake and Performance and Slaughter Procedure. Intake of MR and SF was recorded daily. Calves were weighed every 2 wk. At 27 wk, calves were transported for approximately 40 min (45 km) to a slaughter facility and killed by stunning (captive bolt pistol) and subsequent exsanguination. Measurement of carcass weight and classification of meat color and fat score were performed by a certified employee

Table 2. Analyzed nutrient composition (g/kg of DM) of concentrate, corn silage, and wheat straw fed during the 17-wk experimental period

Nutrient	Concentrate ¹	Corn silage	Wheat straw
DM, g/kg of product	898	297	931
CP ²	137	69	31
Crude fat	67	29	9
Starch	429	312	11
NDF	127	421	794

¹Concentrate composition: 36.2% corn, 20.6% lupins, 20.3% barley, 12.5% carob meal, 4.4% corn gluten meal, 6% premix (lactose carrier, provided per kilogram of concentrate: vitamin A: 4,000 IU; vitamin D: 500 IU; vitamin E: 100 IU; zinc (ZnSO₄): 25 mg; manganese (MnSO₄): 20 mg; iodine (KI): 0.8 mg; iron (FeSO₄): 63 mg; selenium (Na₂SeO₃): 0.15 mg; copper (CuSO₄): 15 mg; cobalt: 0.1 mg; 1.13 g of magnesium (magnesium sulfate), 3.0 g of sodium (NaCl), 8.6 g of calcium (CaCO₃), 3.9 g of potassium (KH₂PO₄).

²N × 6.25.

Table 3. Ingredient composition and analyzed nutrient composition of the experimental milk replacer

Item	
Ingredient, g/kg	
Fat-filled whey powder ¹	394.0
Whey protein concentrate	193.9
Whey	143.3
Delactosed whey	135.0
Soy protein isolate	37.7
Soy protein concentrate	25.0
Acidified whey ²	20.0
Pregelatinized wheat starch	20.0
Vitamin and mineral premix ³	10.0
Calcium formate	9.8
L-Lysine-HCl	5.2
DL-Methionine	2.7
Citric acid	2.0
Mono-ammonium phosphate	1.4
L-Threonine	0.2
Nutrient, g/kg of DM (unless otherwise stated)	
DM, g/kg of product	969.5
CP ⁴	210.0
Crude fat	211.6
Starch	22.3

¹Contained 50% fat from palm oil and coconut oil (80:20, wt/wt).

²Acidified with lactate, provided 5.9 g of lactate per kilogram of the experimental diet.

³Provided per kilogram of the experimental diet: 16.6 g of K, 15.5 g of Cl, 8.3 g of Fe, 6.1 g of P, 5.9 g of Cu (CuSO₄), 5.7 g of Na, 1.3 g of Mg (MgO), 25,000 IU of vitamin A, 4,000 IU of vitamin D₃, 100 IU of vitamin E.

⁴Calculated as N × 6.25.

of the Central Office for Slaughter Livestock Services (BV CBS, Zeist, the Netherlands). Carcass gain was calculated by subtracting the estimated carcass weight at the start of the experimental period from the carcass weight. To estimate carcass weight at the start of the experimental period, dressing percentages obtained at the end of the experiment for the associated SF levels with R:C ratios of 50:50 were used. Meat color was scored on a 10-point scale from 1 (pale) to 10 (red) on the rectus abdominis muscle of the carcass using a handheld Konica-Minolta CR400 spectrophotometer (Konica-Minolta, Tokyo, Japan), as previously described by Hulsege et al. (2001). Fat score of the carcasses was assessed by hypodermic fat coverage on the outside of the carcass and inside the chest cavity on a 5-point scale from 1 (no or very low amounts of fat) to 5 (carcass and chest cavity are covered with fat). The empty rumen weight was recorded. Rumen development was assessed by visual examination of the rumen mucosal surface and the presence and density of rumen papillae, and scored on a 5-point scale from 1 (minimal; few papillae or short papillae) to 5 (extensive; numerous, long and well-developed papillae), by an experienced pathologist-anatomist. Individual scores (i.e., fat, color, rumen development) were averaged per pen and subsequently treated as continuous variables. Abomasal damage was assessed by counting and scoring the size of lesions in the pyloric area of the abomasal wall, and was expressed as a product of counts and size. Lesions (erosions, ulcers, and scars) were categorized as small ($<0.5 \text{ cm}^2$), medium (0.5 to 1.0 cm^2), or large ($>1.0 \text{ cm}^2$) and were assumed to be 0.25, 0.75, and 1.25 cm^2 , respectively.

Chemical Analyses. Samples of MR, concentrate, corn silage, and straw were collected weekly. Corn silage samples were pooled by month; other samples were pooled for the experimental period. All samples were analyzed for DM, CP, starch, NDF (except for MR), and crude fat contents. For determination of DM content, corn silage and concentrate samples were freeze-dried. Concentrate, straw, and corn silage samples were ground to pass a 1-mm screen. Dry matter content was determined by drying to a constant weight according to ISO standard 6496 (ISO, 1998). Kjeldahl N content was determined according to ISO standard 5983 (ISO, 1997). Crude fat content was determined following acid hydrolysis according to ISO standard 6496 (ISO, 1999). The NDF content was analyzed according to Van Soest et al. (1991). Starch content was determined enzymatically as described by Rijnen et al. (2001). Before starch analysis, reducing sugars were extracted from the samples according to the Luff-Schoorl method (NEN, 1974), using 40% ethanol and subsequent hydrolysis in a weak acid environment.

Statistical Analysis

In total, 15 calves were excluded from the experiment: 6 calves during the adaptation period and 9 calves during the experimental period due to clinical sickness ($n = 7$; e.g., lung infection, diarrhea) or death ($n = 2$). Pen was considered the experimental unit, and dependent variables were averaged per pen before statistical evaluation. Dependent variables were analyzed using analysis of covariance (SAS version 9.2; SAS Institute Inc., Cary, NC). The model comprised SF intake as a covariate and the interaction between SF intake and R:C ratio to estimate regression coefficients for both R:C ratios. The main effect of R:C ratio was excluded to obtain a single intercept, which represents the value of the dependent variable when SF intake is zero (i.e., R:C ratio of SF is meaningless). The number of calves in a pen (3, 4, or 5) was included in a weight statement to account for differences in reliability of pen means. Residual carcass gain was included as a covariate in the model to account for within-treatment variation of carcass gain when the dependent variable was DMI from MR, fat score, color score, or live weight gain. Residual carcass gain was calculated for each pen by difference between the pen mean and the treatment mean. When model residuals were not normally distributed, data were transformed to obtain homogeneity of variance. Data are presented as raw means with standard errors of the means, and *P*-values were obtained from analysis of the normally distributed data (after transformation if required). Regression coefficients are presented with their common intercept.

To evaluate time-related changes in MR intake to achieve similar rates of carcass gain, biweekly (every other week) data were analyzed. Biweekly rates of MR intake, expressed as MR intake per kilogram of carcass gain (kg DM of MR/kg of carcass gain), was considered the dependent variable. Fixed effects of SF intake (kg of DM/d) as co-variable, and the interaction between SF intake and R:C ratio on the dependent variable were analyzed for every 2-wk period. The significance of the decline in regression coefficients was determined by analysis of covariance (SAS Institute Inc.) with time (i.e., 2-wk period) as a covariate, including the interaction between R:C ratio and time. Differences were considered significant at $P < 0.05$.

RESULTS

Realized cumulative DMI from SF were very close to targeted DMI (Table 4). Figure 1 shows the effect of R:C ratio on the relationship between total DMI from MR and total DMI from SF over the 17-wk experimental period. The regression coefficients in Figure 1 repre-

sent the change in MR intake (in kg of DM) to achieve similar rates of carcass gain per 1-kg increase in DMI from SF for each R:C ratio. The regression coefficient for the R:C ratio of 50:50 was -0.41 kg of MR/kg of SF and differed ($P < 0.001$) from the regression coefficient for the R:C ratio of 20:80, which was -0.53 kg of MR/kg of SF. Carcass gain during the experimental period, however, increased slightly with SF intake ($P < 0.01$; Table 5), independent of the R:C ratio. Due to unexpected high rates of BW gain of calves at the high SF intakes, the paired-gain objective was not completely achieved. The MR allowance required to achieve the same BW gain for calves at the low SF intakes was beyond the intake capacity of these calves. To correct for differences in carcass gain, the effect of R:C ratio on MR intake per kilogram of carcass gain was analyzed. The regression coefficients were -0.0077 and -0.0086 kg of MR/kg of carcass gain and per kg of SF for R:C ratios of 50:50 and 20:80, respectively (Table 5) and differed ($P < 0.05$) from each other.

The effect of time on the relationship between MR intake, expressed per kilogram of carcass gain, and SF intake is shown in Figure 2. These biweekly regression coefficients were obtained from 2-wk averages of SF intake (Supplemental Figure S1; <http://dx.doi.org/10.3168/jds.2014-8098>), MR intake (Supplemental Figure S2), and carcass gain (Supplemental Figure S3). The regression coefficients, representing the reduction in MR intake per kg of SF per kg of carcass gain for a 2-wk period, decreased with time ($P < 0.05$). The decrease with time was greater for the R:C ratio of 20:80 than for 50:50 ($P < 0.01$).

Figure 1. Relationship between total DMI from solid feed and DMI from milk replacer at 2 roughage-to-concentrate ratios (▲: 50:50, ●: 20:80) in veal calves in a paired-gain design from wk 11 to 27 of the experiment. Each observation includes a pen of 3 to 5 animals. Roughage consisted of 50% corn silage and 50% chopped wheat straw based on DM. The regression coefficient (β) represents the change in milk replacer intake required to maintain growth rate when increasing solid feed intake (kg of DM/kg of DM). Regression coefficients differed ($P < 0.01$) between roughage-to-concentrate ratios (see also Table 5).

Table 4. Dry matter intake from solid feed (SF), milk replacer (MR), and performance of veal calves in a 17-wk experiment aimed to achieve similar rates of carcass gain across levels of SF intake (SF1 to SF4; target DMI from SF of 20, 100, 180, and 260 kg) at each of 2 roughage-to-concentrate (R:C) ratios (50:50 and 20:80)^{1,2}

Item	SF1				SF2				SF3				SF4			
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
No. of pens	4		4		4		4		4		4		4		4	
DMI from SF, kg	20	0.1	20	0.0	93	2.9	94	0.3	167	1.4	172	0.8	239	0.9	248	1.6
DMI from MR, kg	274	6.6	271	0.9	251	6.2	232	1.4	215	3.8	194	1.9	184	1.7	150	0.9
Live weight gain, kg	133	6.9	127	3.2	144	9.2	145	2.9	158	5.1	154	2.9	158	3.2	159	3.8
Carcass gain, kg	74	3.4	74	2.6	80	5.6	80	2.1	88	3.6	84	1.9	87	1.4	85	2.3
Color score ³	4.2	0.06	3.9	0.44	4.8	0.48	4.0	0.56	4.8	0.57	4.5	0.47	5.3	0.14	5.5	0.43
Fat score ³	2.0	0.09	2.2	0.06	2.4	0.31	1.8	0.23	2.2	0.08	2.1	0.06	1.9	0.08	2.1	0.08
Blood Hb, ⁴ mM	4.3	0.15	4.3	0.06	4.7	0.19	5.0	0.14	5.5	0.11	5.6	0.04	5.8	0.18	5.9	0.02
Carcass weight, kg	131	2.6	130	3.3	131	2.1	137	2.2	139	1.5	144	4.4	139	1.7	142	1.8
Live weight, kg	230	3.3	232	6.8	246	3.2	243	8.6	253	2.0	260	6.1	259	3.8	259	4.7

¹Statistical analysis of these data is included in Table 5.

²Roughage consisted of 50% corn silage and 50% chopped wheat straw on a DM basis.

³Meat color was scored on a 10-point scale from 1 (pale) to 10 (red) on the rectus abdominis muscle of the carcass using a handheld spectrophotometer. Fat score of the carcasses was assessed by hypodermic fat coverage at the outside of the carcass and inside of the chest cavity on a 5-point scale from 1 (no or very low amounts of fat) to 5 (the carcass as well as the chest cavity is covered with fat). ⁴Hemoglobin.

Table 5. Effects of incremental DMI from solid feed (SF) on selected response parameters in veal calves at 2 roughage-to-concentrate (R:C) ratios (50:50 and 20:80); the 17-wk experiment aimed to achieve similar rates of carcass gain across levels of SF intake

Response variable	R:C ratio ¹	Intercept ²	β^3			P -value ⁴ SF $\times$ R:C ratio
			Estimate	SE	P -value ⁵	
DMI from milk replacer (MR), kg	50:50	283	−0.409	0.0147	***	***
	20:80		−0.527	0.0146	***	
Carcass gain, kg	50:50	73.2	0.071	0.0137	***	NS
	20:80		0.055	0.0136	**	
DMI from MR per carcass gain, kg/kg	50:50	3.83	−0.0077	0.00048	***	*
	20:80		−0.0086	0.00048	***	
Color score ⁶	50:50	3.84	0.0061	0.00191	**	NS
	20:80		0.0049	0.00190	*	
Fat score ⁶	50:50	2.09	0.0000	0.00060	NS	NS
	20:80		−0.0003	0.00060	NS	
Live weight gain, kg	50:50	129	0.144	0.0113	***	NS
	20:80		0.131	0.01133	***	

¹Roughage consisted of 50% corn silage and 50% chopped wheat straw on a DM basis.
²Estimate of the response variable for calves without SF.
³Regression coefficient β ($y = a + \beta \cdot x$) represents the change in response variable per increase in DMI from SF.
⁴A significant interaction between the DMI from SF and the R:C ratio indicates that the regression coefficient differs between the R:C ratios. The effect of residual carcass gain (observed carcass gain – average carcass gain per treatment) was included for DMI from MR, color score, fat score and live weight gain, and found significant for DMI from MR, fat score, and for live weight gain.
⁵Probability for test whether the regression coefficient (β) equals 0.
⁶Meat color was scored on a 10-point scale from 1 (pale) to 10 (red) on the rectus abdominis muscle of the carcass using a handheld spectrophotometer. Fat score of the carcasses was assessed by hypodermic fat coverage at the outside of the carcass and inside of the chest cavity on a 5-point scale from 1 (no or very low amounts of fat) to 5 (the carcass as well as the chest cavity is covered with fat). Data were transformed (arsin, sqrt) to obtain homogeneity of variance.
† $P < 0.10$; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

Figure 2. Linear regression between the regression coefficients describing the relationship between milk replacer (MR, kg of DM/d) intake, expressed per kilogram of carcass gain, and solid feed (SF, kg of DM/d) intake at 2 roughage-to-concentrate (R:C) ratios (●: 50:50, ■: 20:80) from wk 11 to 27 after set-up in veal calves in a paired-gain design. Each observation represents the regression coefficient at a given time point, based on a 2-wk period, after set-up at 2 wk of age. For both R:C ratios, regression coefficients decreased with time ($P < 0.001$) and this decline was smaller ($P < 0.01$) for an R:C ratio of 50:50 than for 20:80. Roughage consisted of 50% corn silage and 50% chopped wheat straw based on DM.

Table 6. Effects of incremental DMI from solid feed (SF) on postmortem variables at 2 roughage-to-concentrate (R:C) ratios (50:50 and 20:80) in veal calves in a paired-gain set-up

Response variable	R:C ratio ¹	Intercept ²	β^3			P -value ⁴ SF $\times$ R:C ratio
			Estimate	SE	P -value ⁵	
Rumen development score	50:50	1.38	0.0035	0.00062	***	†
	20:80		0.0046	0.00062	***	
Empty rumen weight, kg	50:50	2.73	0.0066	0.00115	***	NS
	20:80		0.0059	0.00115	***	
Abomasal damage, cm ²	50:50	0.80	0.0038	0.00250	NS	NS
	20:80		0.0052	0.00249	*	

¹Roughage consisted of 50% corn silage and 50% chopped wheat straw on a DM basis.

²Estimate of the response parameter for calves without solid feed.

³Regression coefficient β ($y = a + \beta \cdot x$) represents the change in response variable per increase in DMI from solid feed.

⁴A significant interaction between the DMI from SF and the R:C ratio indicates that the regression coefficient differs between the R:C ratios. The effect of residual carcass gain was not significant for any response parameter.

⁵Probability for test if the regression coefficient (β) equals 0.

† $P < 0.10$; * $P < 0.05$; *** $P < 0.001$.

Carcass color score tended to increase with SF intake ($P < 0.10$; Table 5). Fat score of the carcass was unaffected by SF intake and R:C ratio. Live weight gain increased with SF intake ($P < 0.001$) and this increase did not differ between R:C ratios. Rumen development score increased with SF intake ($P < 0.001$), and this increase tended to be greater for the R:C ratio of 20:80 (Table 6). Empty rumen weight increased ($P < 0.001$) with SF intake and ranged between 2.24 and 5.18 kg. The surface area of abomasal damage ranged from 0.1 to 4.3 cm² and increased with SF intake for R:C ratio 20:80 ($P < 0.05$), but not for 50:50, although the interaction was not significant ($P = 0.11$).

DISCUSSION

Utilization of SF for Growth and Effect of R:C Ratio

We aimed to investigate the feeding values of MR, roughage, and concentrates for veal calves in a paired-gain setting, thus avoiding any prior assumptions in feeding values and large differences in nutrient intakes. The feeding value of SF is expressed as the reduction in MR intake (kg of DM) to realize equal rates of carcass gain with increasing SF intake (kg of DM), and can be derived by regression of MR intake and SF intake (Figure 1). For an R:C ratio of 50:50, MR intake decreased by 409 g of DM for each extra kilogram of DM SF; for an R:C ratio of 20:80, this was 529 g DM of MR. Thus, the amount of MR required to realize equal rates of carcass gain was almost 25% lower for an R:C ratio of 20:80 than 50:50, indicating that utilization of SF for growth is increased with the proportion of concentrate in the SF. After correction for the observed increase in carcass gain with SF intake (6.3 kg per 100 kg DM of

SF; $P < 0.001$; Table 5), the average reduction of MR intake to realize equal rates of carcass gain was still lower for the R:C ratio of 50:50 (0.63 kg of MR/kg of SF) than for the R:C ratio of 20:80 (0.70 kg of MR/kg of SF).

Differences in digestibility of energy from concentrates, roughages, and MR contribute, to a large extent, to variation in their feeding value. When assuming additivity of MR and SF, it would not make a difference whether DE originates from MR or SF. Based on this assumption, we calculated the decrease in DE from MR with increasing DE from SF at each of the 2 R:C ratios. The estimated DE content of MR was 18.5 MJ/kg of DM, as calculated from the analyzed gross energy value and a digestibility of gross energy of 96% (van den Borne et al., 2006b; Labussiere et al., 2009b). The estimated DE content of SF was 10.8 MJ/kg of DM for an R:C ratio of 50:50 (Berends et al., 2012a) and 13.1 MJ/kg of DM for an R:C ratio of 20:80 (J. J. G. C. van den Borne, unpublished data). These digestibility studies in veal calves (Berends et al., 2012a; J. J. G. C. van den Borne, unpublished data) used identical R:C ratios and roughage and concentrate sources as in the current study. Based on these estimates, the reduction of MR intake with increasing SF intake would then be 0.58 and 0.71 kg of MR/kg of SF for 50:50 and 20:80, respectively. These calculated values are only slightly different from the average values obtained in the current study (0.62 and 0.69 kg of MR/kg of SF for 50:50 and 20:80, respectively). Differences between SF and MR in postabsorptive utilization of DE could be affected by energy used by visceral tissues (Reynolds et al., 1991a,b), and methane losses with SF intake in veal calves (Berends et al., 2012a). The reduction in MR intake to realize equal rates of carcass gain with

increasing SF intake is close to those calculated based on DE, assuming additivity of feeding values of MR, roughages, and concentrates.

If digestible CP (DCP) were the main driving force for carcass gain, it would not matter whether the DCP originated from MR or SF. Therefore, we calculated the decrease in DCP from MR required for equal carcass gain with increasing DCP for SF at each of the 2 R:C ratios. When assuming DCP contents of MR, SF 50:50, and SF 20:80 at 197, 42, and 66 g/kg based on calf studies (Ortigue et al., 1990; Moody et al., 2007; Labussiere et al., 2009a), the reduction in MR intake with increasing SF intake would be 0.21 kg of MR/kg of SF for an R:C ratio of 50:50 and 0.33 kg of MR/kg of SF for an R:C ratio of 20:80. Hence, the theoretical reduction in MR intake with increasing SF intake is only 34 to 48% of the reduction observed in the current study, suggesting that DE from SF was more limiting than DCP when exchanging MR for SF. In dairy calves, it was shown that at weaning, increasing ME intake resulted in increased weight gain, whereas increasing protein supply had no effect (Journet, 1984). Potential effects of urea recycling were excluded from this calculation. Nitrogen from MR may be reutilized for protein gain due to urea recycling when providing SF (Berends et al., 2014), but the quantitative contribution of urea recycling to protein gain depends on the N level of SF (H. Berends, unpublished data).

Thus, the average reduction in MR intake with increasing SF intake realized throughout the experimental period is in close accordance with the theoretical predictions by exchanging SF for MR based on DE supply. These data indicate that the feeding value of solid feeds for calf diets can be estimated from DE content.

However, this average reduction realized throughout the experimental period does not account for the large variation observed in time. The regression coefficients, representing the reduction in MR intake with increasing SF intake (kg of MR/kg of SF per kg of carcass gain per day) decreased during the experiment for both R:C ratios (Figure 2), indicating that the utilization of SF for growth relative to MR increased with age. Although the regression coefficients decrease with age, a linear fit may not be optimal. The pattern of decline in time, which was similar for both R:C ratios, may need further study of the potential underlying mechanisms. The decline was greater for an R:C ratio of 20:80 than for 50:50 ($P < 0.01$), which may be explained by the inclusion of concentrate or a reduced efficiency of MR utilization or both. Utilization of protein from MR for growth is known to decrease with increasing age in milk-fed calves (Gerrits et al., 1996; van den Borne et al., 2006a), whereas the utilization of SF increased

with age in veal calves between 108 to 164 kg of BW (Berends et al., 2012a). As in dairy calves (Hodgson, 1971), SF intake may increase rumen volume, resulting in greater rumen retention time and degradation. Furthermore, rumen functioning and fermentation were shown to improve with age in calves fed exclusively SF (Devant et al., 2000; Rotger et al., 2005). The latter corresponds with previous observations in veal calves, where early initiation of rumen development was suggested to result in increased nutrient utilization, especially during the second half of the fattening period (Berends et al., 2012b). Additionally, leakage of MR into the rumen, referred to as ruminal drinking, may increase with age (Guilhermet et al., 1975). Increased ruminal drinking could reduce utilization of MR for gain and thus a relatively greater utilization of SF when exchanging SF for MR to obtain equal growth rates. In addition, ruminal drinking may interfere with microbial fermentation processes in the rumen and could thus affect utilization of SF. Finally, urea recycling in milk-fed calves provided with SF increased with increasing age (Berends et al., 2012a), which has been associated with increased utilization of N from MR (H. Berends, unpublished data).

Rumen Development and Abomasal Damage

An increased supply of end products from rumen fermentation, due to either increased SF intake or concentrate inclusion, can be expected to increase papillae development (Tamate et al., 1962). Rumen development score and empty rumen weight both increased with increasing SF intake, which is in agreement with previous studies in veal calves (Morisse et al., 2000; Berends et al., 2012b). Empty rumen weights were in the upper range of or above previously reported values in veal calves of similar age, which may be explained by the lower level of SF intake (<750 g of DM/d) than in the current study ($<3,000$ g of DM/d) (Morisse et al., 2000; Berends et al., 2012b). Inclusion of 30 to 60% roughage (from various sources) at the expense of concentrates decreased empty rumen weight in veal calves at 10 wk of age (Suárez et al., 2007). In the current study, the increase in rumen development score tended to be ($P < 0.10$) greater for an R:C ratio of 20:80 than for a ratio of 50:50, which may be explained by greater concentrations of VFA in the rumen with increasing concentrate supply (Berends et al., 2012b). The surface of abomasal damage increased with SF intake for an R:C ratio of 20:80 ($P < 0.05$), but not for 50:50 (interaction SF intake $\times$ R:C ratio: $P = 0.11$). Other studies showed that provision of SF to milk-fed calves increased the prevalence of abomasal damage,

including pyloric ulcers, when compared with calves fed MR only (Breukink et al., 1991; Mattiello et al., 2002; Brscic et al., 2011). Solid feed particles may exert mechanically abrasive effects on the abomasal mucosa, which may be sensitized due to provision of large volumes of MR. Promoting early rumen development was previously hypothesized to stimulate fermentative degradation of particles; thereby reducing abomasal damage in veal calves (Berends et al., 2012b). In that study, early rumen development reduced the prevalence of large scars in the abomasum compared with late rumen development (6 vs. 20% of calves; Berends et al., 2012b). The current study used a larger contrast in SF intake but did not include roughage proportions over 50%.

CONCLUSIONS

The aim of the current study was to investigate feeding values of MR, roughage, and concentrates for the formulation of veal calf diets with substantial amounts of SF. The quantity of MR fed to realize equal rates of carcass gain was 10% lower for the 20:80 than for the 50:50 R:C ratio, indicating that utilization of SF for gain increased with concentrate inclusion. Averaged over the 16-wk experimental period, the feeding value of MR relative to that of concentrates and roughages was close to that predicted based on their respective DE contents. Nevertheless, the feeding value of SF relative to that of MR increased substantially with age. Therefore, additivity in feeding values of these ration components cannot be assumed. The surface of abomasal damage increased with SF intake for an R:C ratio of 20:80, but not for 50:50. Rumen development score increased with SF intake.

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