Intake and feed utilization in two breeds of pregnant beef cows fed forages with high-fiber concentrations[1]

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ABSTRACT: Hereford and Charolais beef cows (n = 24 per breed) were used to study the effect of breed and to evaluate late-cut reed canarygrass (**RC**) and whole-crop oats plus urea (**WCO**) compared with late-cut timothy (**TG**) with respect to feed intake and digestibility, rumination time, fecal particle size (**PS**) distribution, N excretion, and ruminal microbial CP production (**MCP**). The TG and RC were cut at flowering and WCO at hard dough stage of maturity. Cows were group-housed, 6 groups per breed, and fed 3 diets ad libitum in 3 periods. The study was designed as two 3 × 3 Latin squares amalgamated to form a 3 × 6 rectangle for each breed. All data were statistically analyzed on group level. Indigestible NDF (**iNDF**) and urinary creatinine excretion were used as markers to estimate apparent diet digestibility and daily urine volume, respectively. Fecal PS distribution was determined by dry sieving, and ruminal MCP synthesis was estimated based on urinary output of purine derivatives. The TG diet had a higher apparent digestibility of OM and NDF ($P < 0.001$) than RC and WCO, which did not differ. The TG diet resulted in the greatest daily DMI, followed by WCO and RC ($P < 0.001$). Intake of NDF (**NDFI**, kg/d and % of BW) was greatest for TG, followed by RC and WCO ($P < 0.001$). Rumination time per kg DMI was longest for RC ($P < 0.001$), and RC and WCO resulted in longest rumination time per kg NDFI ($P < 0.001$). The WCO diet resulted in the largest geometric mean fecal PS and proportion of large particles and in the smallest proportion of small particles, whereas the opposite was found for RC, with TG being intermediate ($P < 0.001$). Intakes in kg per day were higher for Charolais than for Hereford ($P = 0.002$), but no breed effect was detected when intake was expressed in relation to BW. Charolais ruminated longer per kg NDFI corrected for BW ($P = 0.02$) and had smaller mean fecal PS ($P = 0.049$) than Hereford. Total N excretion was highest for RC and lowest for WCO ($P < 0.001$). The TG diet stimulated MCP production to a greater extent than RC and WCO ($P < 0.001$). The results indicate that late-cut RC and WCO could be suitable alternatives to late-cut TG for ad libitum feeding of early pregnant beef cows, and that intake was associated with cow BW, but not with breed. The variations in NDF and iNDF concentrations between forage diets were reflected in their effects on intake, rumination, apparent digestibility, and fecal PS.

Key words: beef cow, breed, fecal particle size, forage utilization, reed canarygrass, rumination

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INTRODUCTION

Beef cows are usually fed forage ad libitum for rational reasons. To limit cow intake and costs of production, suitable forage quality for pregnant beef cows with modest nutritive requirements is achieved by delaying the harvest. Late-cut forage is characterized by high NDF concentration and low digestibility, making it possible to utilize the mechanism of rumen fill (Allen, 1996) instead of restrictive feeding to control intake. Timothy (**TG**) is commonly used in mixed grass silages in the Nordic countries, but its presence in beef cow rations is questioned due to its high digestibility. Other high-fiber forages, e.g., late-cut reed canarygrass (**RC**) and whole-crop oats (**WCO**), are proposed alternatives, but are only used in limited parts of the world. Thus, data on their intake potential and utilization in beef cows are limited.

Intake is known to vary with cow BW (Taylor et al., 1986), but may also vary with genotype (Murphy et al., 2008), and breed differences in eating and rumination behavior are suggested to affect NDF digestibility in dairy cows (Aikman et al., 2008). Hereford and Charolais, an early- and a late-maturing beef breed, were historically developed on low- and high-quality forage diets, respectively. Also, Swedish breeding goals still dictate that Hereford should be bred for more nutritionally extensive production than Charolais (NAB, 2018). Thus, the question has been raised if intake and feed utilization in these breeds may differ due to their evolutionary backgrounds. Such information is warranted as it could indicate if feeding recommendations should differ between breeds.

The objectives were to evaluate alternative late-cut forages to late-cut TG, and to study the effect of breed, with respect to feed intake and utilization in beef cows fed ad libitum. Our hypothesis was that feed intake and utilization would be lower for RC and WCO compared with TG and that there would be differences between an early- and a late-maturing beef breed.

MATERIALS AND METHODS

All experimental procedures were complied with the Swedish Animal Welfare Ordinance (SFS 1988:539), Swedish Board of Agriculture regulations and general recommendations on laboratory animals (SJVFS 2012:26), and were approved by the Gothenburg Research Animal Ethics Committee (case number 175-2012). The study was conducted during autumn 2012 at Götala Beef and Lamb Research Centre, south-western Sweden.

Animals and Experimental Design

The study was performed with 48 beef cows, 4 to 8 yr old, of the early-maturing breed Hereford (n = 24) and the late-maturing breed Charolais (n = 24). The cows were grazed on pasture for 6 mo and were then housed and fed grass/clover silage for 1 wk before the experiment started. They were group-housed in a free-stall barn with scraped alleys and straw deep litter. All animals were weighed on 2 consecutive d, without restriction of feed and water, just before the experiment began and between each experimental period. At the start of the experiment, cows were pregnant (3.7 ± 0.8 mo), nonlactating, with BW (mean ± SD) of 689 ± 76 and 766 ± 75 kg for the Hereford and Charolais breeds, respectively.

The study was designed as two 3 × 3 Latin squares amalgamated to form a 3 × 6 rectangle for each breed. There were 3 diets, fed for three 21-d periods. The first 14 d within each period served as the adaption period, followed by a 7-d data collection period. Within breeds, cows were randomly allocated to 6 pens, with 4 animals per pen, resulting in 12 groups in total. Two groups of each breed were randomized to the same diet in each period.

Experimental Diets and Feeding

The 3 experimental forages were as follows: TG silage cut from a sward of 90% to 95% TG (*Phleum pratense* cv. SW Ragnar) and 5% to 10% red clover (*Trifolium pratense* cv. SW Sara, SW Ares) on

a DM basis; RC silage (*Phalaris arundinacea* cv. Palaton) harvested from a monoculture sward; and WCO silage (*Avena sativa* cv. Kerstin). The TG and RC were harvested in the stage of flowering, maturity stage code 61–69 (Gustavsson, A., 2011) of the primary growth on 28 June and 4 July, respectively, and the WCO silage at the hard dough stage, maturity stage code 87 (Zadoks et al., 1974), on 12 August. The TG, RC, and WCO were prewilted to approximately 43%, 48%, and 42% DM, respectively. All forages were preserved in round bales (Krone Combi Pack 1250 MC, Germany) with 8 layers of plastic and with 2 liters of chemical additive (Kofasil Ultra K; nitrite, hexamine, benzoate, sorbate, propionate; Addcon Europe GmbH) added per ton of fresh herbage at baling. The theoretical cutting length of the baler was 70 mm. The WCO silage was supplemented with urea (53.7 ± 1.1 g per cow daily), because of its low CP concentration (45 g/kg DM) to avoid N constraints on rumen microbial fermentation. The urea was suspended in water (7.5 g/liter) and half the daily dose was mixed into the WCO silage (WCO; whole-crop oat + urea) at each feed-out. Cows were fed ad libitum, allowing 10% refusals. Feed was delivered twice a day, at 0800 and 1400 h, and refusals were removed daily. Daily feed intake was recorded on group level. Animals had free access to water and a salt block, and received 100 g of vitaminized minerals per cow and day. All forages were mixed in a Dunker TS 120 mixer (Storti, Netherlands) prior to feeding, to ensure similar particle lengths of all diets. Forage particle size (**PS**) was determined after chopping according to Heinrichs and Kononoff (2002), using sieves with pore sizes of 30, 19, 8, and 1 mm and a solid bottom bowl. The analysis showed no differences in PS between forages.

Sample Collection

During the data collection period (days 15 to 21), feeds and refusals were sampled daily and later pooled to 1 feed sample per diet and period and 1 refusal sample per group and period. Daily intake values were corrected for the concentrations of nutrients in refusals. Diet selection was calculated for each group and period as the difference between NDF concentration in feed and NDF concentration in refusals. Positive and negative values indicated that cows had selected parts that were high and low in NDF concentration, respectively. Feed samples for analysis of fermentation products were collected 4 times per diet and period, immediately after a new silage bale had been opened and mixed, and pooled to 1 sample per diet and period. Fecal samples (approximately 200 g) were collected from each cow once a day (at around 1100 h) on days 17 to 21 and pooled to 1 sample per group and period. Feed, refusal, and fecal samples were stored frozen (−20 °C) before further analysis. Urine spot samples were collected by vulval stimulation from all cows at 0600 and 1300 h on day 19 or 20. An aliquot of 40-mL urine was mixed with 160-mL 0.072*N* H_2SO_4 and immediately frozen (−20 °C). The 2 urine samples were pooled to 1 sample per cow and period before analysis. Urinary creatinine excretion was used as a marker to estimate daily urine output from the urine spot samples (Valadares et al., 1999). Mean creatinine excretion of 0.197 mmol/kg BW, previously determined by total urine collection in mature Hereford cows (Jardstedt et al., 2017), was used to calculate urine volume as follows: Urine volume (L) = [0.197 (mmol/kg BW) × BW (kg)]/creatinine excretion (mmol/liter). Urine volume was then used to estimate daily excretion of urinary N, urea-N, allantoin, and uric acid.

Rumination

A Heatime HR rumination monitoring system (SCR Engineers Ltd., Netanya, Israel) was used to individually record rumination time during the experiment. The system consists of a sensor attached dorsally to a collar on the left side of the cow's neck, which records the sound pattern of rumination and regurgitation. This information is processed into individual rumination times displayed in minutes per 2-h interval at whole hours by the software. Data were collected twice daily from the sensor units by a hand-held antenna. Mean rumination time per cow and day per group were calculated for each data collection period.

Fecal Particle Size

Three fecal subsamples with a size of 7 g each were placed in nylon bags with a pore size of 10 µm and washed in a washing machine at 40 °C for 120 min, using a commercial laundry detergent to render protein, fat, and starch water soluble. The samples were then freeze dried, and PS distribution was determined by horizontal shaking and sieving into 6 size fractions, as described by Nørgaard et al. (2004) and Jalali et al. (2012). Fecal DM was determined on 2 replicates (4.5 g) for each group and period by oven-drying at 100 °C for 24 h and was used to estimate fecal particle DM (**PDM**). The PDM is defined as the proportion of fecal DM that

is left after washing and freeze-drying. The proportion of PDM retained on each sieve fraction was estimated as the weight of each fraction. Whole grains were observed in sieving fraction 2.36 mm for the WCO diet, which were removed and not included in the calculations. The arithmetic mean PS (**APS**) and geometric mean PS (**GPS**) were estimated according to Waldo et al. (1971). The median and the 95 percentile PS were calculated as described by Nørgaard (2006).

Chemical Analysis and Calculations

Feed, refusal, and fecal samples were analyzed for DM, CP, NDF, ADF, ADL, indigestible NDF (**iNDF**), and in vitro organic matter digestibility (**IVOMD**). Samples (200 g) of feed and refusals were dried in a drying cabinet at 60 °C for 24 h for DM determination and further analysis. DM of each forage was also determined daily during the data collection periods for calculation of DMI. Fecal samples (400 g) were dried at 60 °C for 48 h for further analysis. Ash was determined for all materials by combustion at 525 °C for 16 h.

Dried feed, refusal, and fecal samples were milled (1-mm screen) before sequential analysis of NDF, ADF, and ADL in an ANKOM^{200} fiber analyzer (Ankom Technology, Fairport, NY, USA) according to Van Soest et al. (1991). The NDF analysis was modified by adding heat-stable α-amylase (Novozymes, Bagsvaerd, Denmark), whereas sodium sulfite was omitted. Reported concentrations of NDF, ADF, and ADL were corrected for residual ash after the ADL treatment.

Forage concentrations of iNDF were determined in situ on dried and milled samples (1.5-mm screen). The samples were incubated in polyester bags with a pore size of 12 µm for 288 h in 2 rumen-fistulated dairy cows fed a standard maintenance diet (Åkerlind et al., 2011). The concentration of potentially digestible NDF (**pdNDF**; g/kg DM) in feed and feces was calculated by subtracting the concentration of iNDF (g/kg DM) from total NDF (g/kg DM).

Concentrations of iNDF in feed, refusals, and feces were used as an intrinsic marker to estimate total-tract apparent digestibility of OM, NDF, ADF, pdNDF, and CP. The marker iNDF was determined by in vitro analysis according to Goeser and Combs (2009). Dried samples were milled to 1 mm, and 0.250 g of sample was incubated in Ankom F57 filter bags for 240 h at 39 °C in a Daisy II-incubator. The samples were analyzed in duplicates. The inoculum (rumen fluid + buffer) was changed every second day during the incubation. Rumen fluid was collected from 2 nonlactating dairy cows fed a standardized diet of hay ad libitum and 2 kg of concentrate per cow and day. The subsequent NDF analysis included α-amylase, but not sodium sulfite. Total feces output (kg) was calculated as iNDF consumed (g/d) corrected for refusals, divided by iNDF concentration (g/kg) in feces. Digestibility of OM, NDF, ADF, and pdNDF was calculated by the following equation: Digestibility = (intake of nutrient − fecal output of nutrient)/intake of nutrient.

The IVOMD of TG and RC was analyzed according to the VOS (ruminal fluid digestible organic matter) method (Åkerlind et al., 2011), where 0.5-g dried sample was incubated in 49-mL buffer and 1-mL rumen fluid at 38 °C for 96 h. For WCO, IVOMD was determined by the IVOS (in vitro organic matter digestibility) method based on the work of Tilley and Terry (1963).

Concentrations of N were determined with the Kjeldahl method on fresh, pooled samples of feed and refusals and freeze-dried samples of feces (AOAC, 2012). The CP concentration was calculated as total N × 6.25. The concentration of starch in WCO was analyzed by an enzymatic method where starch is degraded with amylase and analyzed as glucose. The free glucose is subtracted and is not included in the starch (Larsson and Bengtsson, 1983).

Silage concentrations of volatile fatty acids and ethanol were determined with gas chromatography (Weiss, 2001), lactic acid with HPLC (Weiss and Kaiser, 1995), and ammonia concentration was determined colorimetrically based on the Berthelot reaction by use of a continous flow analyser (SKALAR, analytical B.V., Netherlands). Concentrations of water-soluble carbohydrates (**WSC**) were determined according to Lengerken and Zimmermann (1991), and pH measurements were performed potentiometrically using a calibrated pH electrode.

Concentrations of allantoin, uric acid, and creatinine in urine were analyzed by HPLC according to Shingfield and Offer (1999), but with the modification of using a Kinetex XB-C18 column (150 × 4.6 mm, 5 µm) and a second mobile phase containing methanol, acetonitrile, and distilled water (45:45:10). Urinary N concentration was analyzed with a Kjeldahl procedure and urinary urea-N concentration by HPLC (LKS, 2006).

Statistical Analysis

Data on intake, selection, digestibility, rumination time, fecal characteristics, and urinary excretion parameters were analyzed as means at group

level using the mixed procedure in SAS (SAS ver. 9.3, SAS Institute, Cary, NC, USA, 2012). The statistical model used was as follows:

$$y_{hijkl} = \mu + \pi_h + \mathrm{r}_i + \tau_j + \gamma_k + (\mathrm{r}\tau)_{ij} + s_{l(i)} + e_{ijkl}$$

where y_{hijkl} is the dependent variable, μ is the overall mean, π_h is the fixed effect of period (h = 1, 2, 3), r_i is the fixed effect of breed (i = 1, 2), τ_j is the fixed effect of forage (j = 1, 2, 3), γ_k is the fixed effect of carryover (k = 1, 2, 3), $s_{l(i)}$ is the random effect of group (l = 1, …, 6), and e_{ijkl} is the residual error.

Interactions between breed and period, and between breed and carryover, were tested initially, but these effects were not significant ($P > 0.10$) for any of the variables analyzed and were thus excluded from the model. The F-values were significant at $P < 0.05$ and tendencies were assumed at $0.05 < P < 0.10$. For significant F-values, least-squares means (LSmeans) of treatments were compared pairwise using Tukey's test. Data reported are LSmeans and standard error of the mean.

RESULTS

Feed Intake, Digestibility, and Selection

The nutrient composition of the experimental forages is shown in Table 1. The aim of urea supplementation of the WCO silage was to increase the CP concentration to 60 g/kg DM, which is suggested to be the minimum amount required to avoid restricting rumen microbial fermentation (Mertens, 1994). However, the cows consumed more DM than expected and the amount of urea added per cow and day was therefore diluted, resulting in a mean CP concentration of 58 g/kg DM for the WCO diet.

The interaction between breed and diet was only significant for intakes (kg/d) of DM (P = 0.048) and OM (P = 0.040), where Hereford had lower DM and OM intakes of TG and WCO than Charolais, whereas DM and OM intakes of RCO were similar between the breeds. However, the significance of the interaction was negligible in comparison to the main effects (Table 2) and is, therefore, not discussed further. When averaged over breeds, TG resulted in the greatest intake of DM in kg/d and in percentage of BW, followed by WCO and RC (Table 2). Feeding TG resulted in the greatest intake of digestible OM, with no differences observed between WCO and RC. The greatest NDF intake (**NDFI**) in kg/d and in percentage of BW was observed for TG and the lowest for WCO. Intake of iNDF was greatest for WCO and lowest for TG, but when expressed as a percentage of BW, WCO did not differ from RC. The NDFI was 1.03 ± 0.13% of BW when averaged across breed and diet. RC resulted in the greatest

Table 1. Mean (± SD) content of nutritional components of the 3 experimental forages

Item[1]	Timothy	Reed canarygrass	Whole-crop oat
DM, g/kg	459 ± 17.9	529 ± 24.3	443 ± 5.1
Ash, g/kg DM	60.1 ± 6.15	40.1 ± 4.61	61.7 ± 5.59
CP, g/kg DM	82.6 ± 4.06	119 ± 1.4	45.1 ± 4.91
NDF, g/kg DM	585 ± 16.4	651 ± 11.3	546 ± 55.7
ADF, g/kg DM	353 ± 19.5	384 ± 2.7	327 ± 43.2
ADL, g/kg DM	46.1 ± 8.36	57.5 ± 9.87	41.5 ± 1.67
iNDF, g/kg DM	134 ± 4.4	205 ± 5.8	199 ± 1.7
iNDF, g/kg NDF	222 ± 10.0	310 ± 3.0	343 ± 21.9
pdNDF, g/kg DM	451 ± 18.5	446 ± 5.8	347 ± 54.1
ADL:NDF	0.08 ± 0.012	0.09 ± 0.016	0.08 ± 0.005
iNDF:ADL	2.99 ± 0.600	3.65 ± 0.643	4.80 ± 0.152
In vitro OMD, % of OM	76.8 ± 1.52	62.9 ± 1.92	50.1 ± 0.25
Starch, g/kg DM	–	–	106 ± 29.2
WSC, g/kg DM	126 ± 21.9	40.4 ± 4.45	67.3 ± 11.73
pH	4.45 ± 0.00	4.51 ± 0.00	5.08 ± 0.534
Ethanol, g/kg DM	3.4 ± 0.39	1.9 ± 0.29	1.9 ± 0.22
Lactic acid, g/kg DM	35.1 ± 5.67	26.3 ± 3.87	13.5 ± 6.53
Acetic acid, g/kg DM	8.8 ± 1.36	6.5 ± 0.27	4.4 ± 0.65
Ammonia-N, g/kg total N[2]	94.0 ± 8.00	84.1 ± 16.8	88. ± 7.11

Values are means of n = 3 samples per silage type.

[1]iNDF = indigestible NDF determined by in situ analysis; pdNDF = potentially digestible NDF calculated as total NDF (g/kg DM) − iNDF (g/kg DM); OMD = OM digestibility; WSC = water-soluble carbohydrates. Butyric acid was not detected.

[2]Including N from the nitrite and hexamine in the silage additive.

Table 2. Body weight, intake, apparent digestibility coefficients, and rumination time in beef cows of Hereford (HE) and Charolais (CH) breeds fed timothy silage (TG), reed canarygrass silage (RC), and whole-crop oat silage plus urea (WCO)

	Diet				Breed			*P*-value[3]	
Item[1]	TG	RC	WCO	SEM[2]	HE	CH	SEM[2]	Diet	Breed
BW, kg	743	738	740	4.89	700	780	6.52	0.200	<0.001
Intake									
DM, kg/d	14.9[a]	11.5[c]	12.3[b]	0.15	12.3	13.4	0.19	<0.001	0.002
OM, kg/d	14.0	11.1	11.6	0.13	11.7	12.7	0.17	<0.001	0.001
DOM, kg/d	9.09[a]	5.14[b]	5.64[b]	0.224	6.45	6.80	0.202	<0.001	0.228
NDF, kg/d	8.73[a]	7.52[b]	6.77[c]	0.107	7.35	8.00	0.106	<0.001	0.001
iNDF, kg/d	2.00[c]	2.36[b]	2.44[a]	0.031	2.17	2.36	0.039	<0.001	0.005
CP, kg/d[4]	1.23[b]	1.38[a]	0.70[c]	0.022	1.06	1.14	0.025	<0.001	0.033
DM, % of BW	2.00[a]	1.56[c]	1.67[b]	0.023	1.72	1.76	0.029	<0.001	0.369
DOM, % of $BW^{0.75}$	6.40[a]	3.65[b]	3.97[b]	0.150	4.74	4.60	0.130	<0.001	0.441
NDF, % of BW	1.18[a]	1.02[b]	0.92[c]	0.013	1.05	1.03	0.014	<0.001	0.237
iNDF, % of BW	0.27[b]	0.32[a]	0.33[a]	0.005	0.31	0.30	0.006	<0.001	0.442
Digestibility coefficients									
OM	0.65[a]	0.47[b]	0.48[b]	0.019	0.54	0.52	0.017	<0.001	0.401
NDF	0.63[a]	0.49[b]	0.42[b]	0.030	0.53	0.50	0.023	<0.001	0.274
ADF	0.62[a]	0.49[b]	0.42[b]	0.032	0.53	0.49	0.026	<0.001	0.221
pdNDF	0.80[a]	0.72[ab]	0.63[b]	0.037	0.74	0.69	0.028	0.013	0.226
CP	0.57[a]	0.58[a]	0.35[b]	0.025	0.51	0.49	0.023	<0.001	0.516
Rumination time									
Min/d	598[a]	582[a]	533[b]	16.1	545	596	17.9	0.003	0.066
Min/kg DM intake	40.3[b]	50.7[a]	43.4[b]	1.48	44.8	44.8	1.73	<0.001	0.988
Min/kg NDF intake	68.6[b]	77.5[a]	79.1[a]	2.21	74.9	75.2	2.53	<0.001	0.941
Min/kg iNDF intake	301[a]	248[b]	220[c]	9.0	257	257	10.3	<0.001	0.992
Min/NDF intake per 100 kg BW	509[b]	569[a]	582[a]	15.2	522	585	17.2	<0.001	0.024
Min/kg DOM intake	66.3[c]	113.3[a]	105.4[b]	5.35	93.7	96.3	5.43	<0.001	0.732

[a–c]Means for the effect of diet within rows with different superscripts are significantly different ($P < 0.05$).

[1]DOM = in vivo digestible OM estimated from apparent in vivo OM digestibility; iNDF = indigestible NDF determined by in situ analysis; $BW^{0.75}$ = metabolic body size, pdNDF = potentially digestible NDF calculated as total NDF (g/kg DM) − iNDF (g/kg DM).

[2]Standard error of the mean.

[3]The diet-by-breed interaction is significant for daily intake of DM ($P = 0.48$) and OM ($P = 0.40$).

[4]Including CP from the urea supplement on the WCO diet, providing 13 g CP/kg DM.

daily intake of CP, whereas WCO gave the lowest CP intake.

Intakes of DM, NDF, and iNDF in kg per day were consistently greater for Charolais than for Hereford cows (Table 2), but no breed effect was detected for intake of digestible OM or when intake was expressed in relation to BW.

Apparent digestibility of OM, NDF, ADF, pdNDF, and CP differed among forage types, but not between breeds (Table 2). The digestibility of OM, NDF, and ADF was greater for TG than for RC and WCO, which did not differ. The TG diet also had greater digestibility of pdNDF than WCO. The digestibility of CP was lower for WCO than for TG and RC, which did not differ.

Cows sorted out WCO particles with a low NDF concentration, as indicated by 32.5 g higher NDF per kg DM in the refusals compared with the silage fed ($P = 0.013$) (Figure 1). In contrast, the NDF per kg DM was 21.8 and 10.3 g lower in the refusals compared with the silage fed for the TG and RC diets, respectively. The difference between the NDF concentration in feed and refusals was larger for WCO than for TG ($P = 0.014$) and tended to be larger for WCO than for RC ($P = 0.054$), with no difference observed between TG and RC. The variation in the differences in NDF concentration between feeds and refusals among cow groups was greatest when cows were fed WCO (Figure 1).

Rumination

Daily rumination time and rumination time relative to intake of DM, NDF, iNDF, and digestible OM differed between the 3 diets, when averaged over breeds (Table 2). Cows fed the RC and TG diets

ruminated 9% and 12% longer per day, respectively, than cows fed WCO. RC resulted in the longest rumination time per kg DM, with no differences observed between TG and WCO. There was no difference in rumination time per kg NDFI between the WCO and RC diets, which resulted in longer rumination times than TG. Rumination time per kg digestible OM intake was longest for RC and shortest for TG. When corrected for BW, rumination time per kg NDFI was 6 min longer for Charolais than for Hereford. Charolais also tended (P = 0.066) to ruminate longer per day than Hereford.

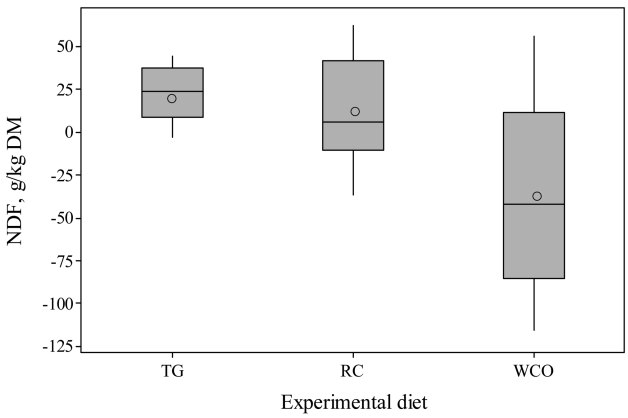

Figure 1. Box-plot of the differences in NDF concentrations (g/kg DM) between feed and refusal (feed minus refusal, n = 12) for 3 diets; timothy silage (TG), reed canarygrass silage (RC), and whole-crop oat silage plus urea (WCO), averaged across 2 breeds of beef cows. For each box, the horizontal line represents the median and the circle represents the mean.

Fecal Particle Size

Fecal characteristics, PS in PDM, and the distribution of PDM in the different sieves differed among diets (Table 3). The concentration of DM in feces and the proportion of PDM in fecal DM were highest when feeding WCO and RC (Table 3). There was no effect of diet on fecal concentrations of NDF, whereas fecal concentrations of N were higher for TG and RC than for WCO. The WCO diet resulted in the highest median, APS, GPS, and 95 percentile PS values. Feces from cows fed RC had the lowest median and GPS values. There was no difference between TG and RC diets for the APS and 95 percentile values. Diet had a significant effect on fecal PS distribution (Table 3) with the WCO diet resulting in the greatest proportion of large particles (≥1.00 mm) and smallest proportion

Table 3. Fecal characteristics, overall fecal particle size and proportion of fecal particles in the individual sieving fractions in beef cows of Hereford (HE) and Charolais (CH) breeds fed timothy silage (TG), reed canarygrass silage (RC), and whole-crop oat silage plus urea (WCO)

	Diet				Breed			P-value[3]	
Item[1]	TG	RC	WCO	SEM[2]	HE	CH	SEM[2]	Diet	Breed
Fecal characteristics									
DM, %	13.3[b]	14.1[a]	14.4[a]	0.22	13.9	14.0	0.26	<0.001	0.831
PDM g/kg DM	705[b]	753[a]	777[a]	8.73	746	744	6.94	<0.001	0.843
NDF, g/kg DM	598	601	568	18.3	580	597	14.6	0.365	0.383
N, g/kg DM	15.6[a]	15.0[a]	10.5[b]	0.21	13.7	13.7	0.19	<0.001	0.989
Fecal particle size (mm)									
Median	0.350[b]	0.333[c]	0.388[a]	0.0046	0.361	0.354	0.0044	<0.001	0.273
Arithmetic mean	0.438[b]	0.414[b]	0.497[a]	0.0080	0.461	0.439	0.0073	<0.001	0.046
Geometric mean	0.238[b]	0.208[c]	0.281[a]	0.0048	0.250	0.235	0.0049	<0.001	0.049
95 percentile	1.118[b]	1.041[b]	1.310[a]	0.0452	1.207	1.106	0.0406	<0.001	0.091
Sieving fraction[4]									
2.36 mm	0.31	0.34	0.43	0.174	0.53	0.20	0.137	0.849	0.098
1.00 mm	3.69[b]	2.32[c]	6.79[a]	0.354	4.45	4.08	0.273	<0.001	0.315
0.50 mm	16.3[b]	12.8[c]	23.0[a]	0.58	18.4	16.4	0.64	<0.001	0.048
0.212 mm	44.1[a]	41.3[b]	40.4[b]	0.54	41.7	42.1	0.43	<0.001	0.533
0.106 mm	25.0[b]	29.9[a]	19.8[c]	0.55	24.3	25.5	0.54	<0.001	0.106
0.0 (bottom bowl)	11.7[b]	13.4[a]	9.67[b]	0.429	10.7	11.7	0.44	<0.001	0.119
≥1.00 mm	4.00[b]	2.66[c]	7.23[a]	0.371	4.98	4.28	0.313	<0.001	0.117
<0.50 mm	79.7[b]	84.6[a]	69.8[c]	0.86	76.7	79.4	0.88	<0.001	0.048

[a–c]Means for the effect of diet within rows with different superscripts are significantly different (P < 0.05).

[1]PDM = proportion of fecal particles left after washing and freeze-drying.

[2]Standard error of the mean.

[3]The interaction between breed and forage is nonsignificant for all variables analyzed.

[4]Whole grains are not included in the calculations for the WCO diet.

of small particles (<0.50 mm). The opposite result was observed for RC, with TG being intermediate. The largest proportion of particles was retained on the 0.212-mm sieve for all diets.

Hereford cows had larger APS and GPS values, a larger proportion of fecal particles retained on the 0.50-mm sieve, and a lower proportion of small particles (<0.50 mm) compared with Charolais.

Excretion of N in Urine and Feces

Feeding RC resulted in the highest N intake and the greatest excretion of urinary N, followed by TG and WCO, when averaged over breeds (Table 4). In addition, RC gave the highest urinary excretion of urea-N, with no differences observed between TG and WCO. Fecal N excretion was lower for cows fed WCO compared with cows fed TG and RC, which did not differ. Urinary excretion parameters were not affected by breed, but Hereford cows tended ($P = 0.085$) to excrete a higher proportion of consumed N as N in urine than Charolais. Charolais had higher N intake and a tendency to higher ($P = 0.053$) fecal N output than Hereford. However, the effect of breed was not significant when N intake and fecal N excretion were corrected for BW (0.023% of BW and 0.11 g/kg BW, respectively).

Urinary Purine Derivatives Excretion

Urinary excretion of allantoin and purine derivatives (PD; allantoin + uric acid) was highest for cows fed TG, followed by WCO and RC (Table 4). Urinary output of PD per kg digestible OM intake was higher for cows fed WCO and RC than for cows fed TG. There was no effect of breed on any of the PD excretion parameters.

DISCUSSION

Digestibility and Intake—Effect of Diet

The results on intake clearly demonstrated that replacing common late-cut TG by late-cut RC or late-cut WCO supplemented with urea decreased intake in beef cows fed ad libitum. Intake in cattle fed high-fiber forages is expected to mainly be limited by rumen fill, which is affected both by NDF concentration and NDF digestibility, i.e., concentration of iNDF in NDF (Allen, 1996). Silage DMI has been shown to be more closely related to iNDF concentration than total NDF, demonstrating the importance of fiber quality on silage DMI (Huhtanen et al., 2007). Both concentration and digestibility of NDF vary within forage species, e.g., due to maturity stage at harvest (Cherney et al., 1993), but also among forage species, e.g., because of differences in histological appearance (Van Soest, 1994). The higher intake of TG compared with RC could be attributed to the 28% lower concentration of iNDF per kg NDF of the former (Huhtanen et al., 2007), which resulted in 29% greater apparent NDF digestibility and 36% greater apparent OMD

Table 4. Intake of N, urine volume, N excretion in urine and feces, and urinary excretion of purine derivatives (PD; allantoin + uric acid) in beef cows of Hereford (HE) and Charolais (CH) breeds, fed timothy silage (TG), reed canarygrass silage (RC), and whole-crop oat silage plus urea (WCO)

	Diet				Breed			*P*-value[2]	
Item	TG	RC	WCO	SEM[1]	HE	CH	SEM[1]	Diet	Breed
N intake, g/d[3]	197[b]	221[a]	111[c]	3.6	170	183	4.0	<0.001	0.033
Urine volume, liters	8.62[a]	6.84[b]	5.94[b]	0.564	7.79	6.48	0.667	<0.001	0.187
Urinary N, g/d	47.4[b]	80.8[a]	32.2[c]	3.01	56.3	50.6	3.45	<0.001	0.258
Urinary urea-N, g/d	19.6[b]	54.4[a]	14.3[b]	2.33	31.3	27.6	2.48	<0.001	0.292
Urinary N output, % of N intake	24.2[c]	37.4[a]	31.3[b]	1.63	33.7	28.3	2.02	<0.001	0.085
Fecal N, g/d	84.3[a]	94.4[a]	70.3[b]	3.75	77.8	88.2	3.55	<0.001	0.053
Total N excretion, g/d	131[b]	175[a]	102[c]	5.06	134	138	5.06	<0.001	0.505
Allantoin, mmol/d	125[a]	96.2[c]	111[b]	9.24	107	114	12.6	<0.001	0.715
Uric acid, mmol/d	16.7[a]	13.5[b]	12.1[c]	1.16	13.1	15.1	1.59	<0.001	0.382
PD, mmol/d	141[a]	110[c]	123[b]	10.2	120	129	13.9	<0.001	0.664
PD, mmol/kg DOMI[4]	15.7[b]	21.9[a]	22.9[a]	1.85	19.8	20.4	2.34	<0.001	0.860

[a-c] Means for the effect of diet within rows with different superscripts are significantly different ($P < 0.05$).

[1]Standard error of the mean.

[2]The interaction between breed and forage is nonsignificant for all variables analyzed.

[3]Including N from the urea supplement on the WCO diet, providing 2.1 g N/kg DM.

[4]DOMI = in vivo digestible OM intake estimated from apparent in vivo OM digestibility.

of TG compared with RC. The TG was harvested at similar maturity stage as RC (flowering), but 6 d earlier. The earlier harvest of TG may have contributed to its greater OMD, because RC has been shown to mature more rapidly and decline faster in in vitro DM digestibility than TG (Collins and Casler, 1990; Cherney et al., 1993). However, because both forages were cut at flowering, differences in fiber composition and apparent OMD between TG and RC could have also been driven by intrinsic properties of the 2 crops. Previous studies have shown that when cut at the same stage of maturity, TG had lower NDF and iNDF concentrations and greater in vitro digestibility of DM and NDF than RC (Collins and Casler, 1990; Cherney et al., 1997).

The greater intake of TG compared with WCO was probably the result of a lower proportion of iNDF per kg NDF in TG (Huhtanen et al., 2007). Even though WCO and RC had similar concentrations of iNDF per kg NDF and similar apparent digestibility of NDF and OM, feeding WCO resulted in higher intake than RC. The explanation could be that the WCO diet caused less rumen fill than the RC diet, because of its lower concentration of NDF (Huhtanen et al., 2007).

Unlike forage grasses, fiber concentration of whole-crop cereals decreases with advancing maturity postheading, because of starch accumulation during grain filling (Wallsten et al., 2010). The higher starch content compensates the reduced fiber digestibility of stems and leaves at increased maturity, resulting in relatively constant OM digestibility as whole-crop cereals mature. Yet, apparent OMD of WCO was lower than previously reported for WCO cut at the early dough stage (63% OMD; Wallsten et al., 2010). The WCO in the present study was cut at the hard dough stage, which, in contrast to Wallsten et al. (2010), resulted in a great loss of kernels at mowing and baling. Hence, the reason for the lower OMD of WCO in this study compared with the study of Wallsten et al. (2010) was probably related to its lower concentration of starch, 103 vs. 137 g/kg DM, in addition to a lower digestibility of NDF, 42% vs. 60%.

It is possible that intake of WCO was restricted due to ruminal N deficiency, because of the low CP concentration of WCO. Intake is expected to be depressed when forage CP concentration is below 60 to 80 g/kg DM, because of inhibited microbial fiber digestion (Hoover, 1986; Mertens, 1994). Therefore, the intake potential of WCO might not have been fully exploited in the present study. However, neither values of PD excretion, mmol/d or PD/kg digestible OM intake, were smallest among cows fed WCO, which implies that N deficiency might not have been a restricting factor.

A negative relationship between alkaloid concentration in RC and voluntary intake by lambs has been demonstrated by Marten et al. (1976). Even though a low-alkaloid variety of RC was used in the present study, the possibility that the presence of alkaloids affected RC palatability and that it was a contributing reason for the lower DMI of RC compared with TG and WCO cannot be excluded.

Cows selected the less fibrous parts of WCO, as found previously by Wallsten et al. (2009). No evidence of such selective feeding behavior was detected when cows were fed TG or RC, which could be explained by the more heterogeneous appearance of WCO facilitating sorting.

Digestibility and Intake—Effect of Breed

Intake appeared to be related to the different BW of the 2 breeds, as the breed difference in daily consumption was no longer present when intake was related to BW, suggesting that intake was similarly constrained in both breeds. Likewise, Murphy et al. (2008) reported that observed differences in daily DMI between lactating Charolais and Limousin cows were an effect of differences in BW rather than an effect of breed. Furthermore, Taylor et al. (1986) found that BW explained 80% of the variation in voluntary intake when compared across 25 breeds of growing cattle. In the present study, BW and DMI were 80 and 1.1 kg higher, respectively, for Charolais than for Hereford when averaged across diets. This is in agreement with results reported by Walker et al. (2015), where nonlactating Angus-cross beef cows were divided into a heavy and a light group, differing by 74 kg in BW and 1.1 kg in DMI. Likewise, NRC (2000) predicts that DMI should increase by 1.2 kg when cow BW increases by 80 kg when animals are in similar stages of production.

Apparent diet digestibility was similar for the Hereford and Charolais breeds, which may be expected, as no differences in intake of DM or NDF per kg BW were observed. Yet, the smaller fecal PS in Charolais feces compared with Hereford feces suggested that apparent OMD should have been greater in Charolais compared with Hereford, but no such effect was detected.

Rumination and Fecal Characteristics—Effect of Diet

Forage PS reductions through chewing and increases in particle density through fermentation

are 2 processes necessary for digesta to be able to pass out of the rumen. Hence, intake of coarse forages might be limited to some extent by the capacity of the ruminant to mechanically decrease PS through chewing (Van Soest, 1994). When cows were fed WCO, daily rumination time was within the daily limits of 8 to 9 h that cattle normally spend ruminating (Welch, 1982). Feeding TG and RC resulted in rumination times that approached the proposed maximum of 10 h/d for cattle (Welch, 1982), implying that DMI of these diets might have been restricted by the extensive time needed for mastication.

Feeding RC resulted in longer rumination time per kg DMI than TG and WCO, which could be attributed to its higher concentration of NDF (Nørgaard et al., 2010; Schulze et al., 2014). Rumination time per kg NDFI was 13% to 15% longer for RC and WCO compared with TG, which probably was associated with the higher iNDF concentration per kg NDF of those diets (Rinne et al., 1999; Schulze et al., 2015). In contrast, Rinne et al. (2002) observed no differences in rumination time per kg NDFI with increasing iNDF to NDF ratio in grass silages fed to dairy cows.

The higher PDM value of feces from cows fed RC and WCO reflected the lower apparent OMD of these diets, indicating that PDM could be a measure of diet OMD. This result agrees with a previous report of increased fecal PDM value in heifers fed grass silage of increased maturity, i.e., higher lignification and lower digestibility (Schulze et al., 2015).

Mastication during eating and rumination are the main causes of feed PS reduction, as principally no degradation occurs in the lower digestive tract. The PS profile found in feces is, therefore, representative of the size distribution of particles leaving the rumen (Rinne et al., 2002). The forage diets in the present study resulted in markedly different fecal PS profiles. Increased lignification (i.e., increased ADL-to-NDF ratio) of grass silages has been shown to linearly increase the mean and median fecal PS and linearly decrease the proportion of small particles in sheep and cattle (Jalali et al., 2012; 2015). Therefore, it was unexpected that the WCO diet resulted in larger fecal PS than the grass silage-based diets, because the ADL-to-NDF ratio of the WCO fiber was similar to that of TG and RC. Lignin is the key element in the cell wall that limits forage digestibility. For lignin to exert its effect cross-linkage with cell wall polysaccharides by ferulic acid bridges may be a prerequisite and this cross-linking effect on fiber digestibility might be more important than lignin concentration (Jung and Allen, 1995). Whole-crop cereals and grass silages differ greatly in morphology. Thus, it could be assumed that they also exhibit large differences in the structure and composition of their cell walls. This assumption was partly supported by the greater iNDF-to-ADL ratio of WCO compared with TG and RC (Thorstensson et al., 1992). The WCO lignin appears, therefore, to be more inhibitory to digestion of NDF per unit of lignin than the TG and RC lignin, limiting the susceptibility of the WCO fiber to degradation by mastication and microbial fermentation.

The digesta particles of RC were more reduced in size than the digesta particles of TG, despite a similar ADL-to-NDF ratio and a numerically higher iNDF-to-ADL ratio of RC. The reduced fecal PS could be explained by the longer rumination time per kg NDFI of RC. Another contributing factor might have been a greater brittleness of the RC fiber as increased maturity of grass silage (i.e., increased lignification) have been proposed to increase the fragility of grass feed particles (Rinne et al., 2002). Additionally, the larger proportion of large particles in feces from cows fed TG compared with cows fed RC may be explained by the greater NDFI per kg BW of TG, in accordance with previous findings (Schulze et al., 2014; Jalali et al., 2015).

Rumination and Fecal Characteristics—Effect of Breed

Cows of the Charolais breed ruminated longer time per kg NDFI corrected for BW and tended to ruminate longer time per day than the smaller Hereford breed. This result was the opposite of what could be expected, as increased body size has previously been related to shorter rumination time per kg NDFI in cattle (Welch, 1982; Bae et al., 1983; Nørgaard et al., 2010).

An explanation for the differences in rumination time between Charolais and Hereford might be that the 2 populations have evolved in different environments. Foraging behavior in cattle has been shown to differ between breeds (Hessle et al., 2008) and strains within breeds (McCarthy et al., 2006) due to origin. Hereford originally evolved in a harsher environment than Charolais. In addition, Swedish breeding goals still dictate that the Hereford breed should be bred for a more nutritionally extensive production than the Charolais breed (NAB, 2018). Therefore, it is plausible that certain foraging traits, e.g., rumination, have been developed differently

for the 2 breeds, in order for them to successfully adapt to prevailing circumstances.

This statement is supported by the theory of resource allocation, which explains behavioral modifications towards less energy demanding behaviors in a biological evolutionary context (Beilharz et al., 1993). An animal has a limited quantity of resources available to be allocated to various biological processes. During evolution, animals have adapted to their environment and the available resources have been optimally partitioned between those processes to maximize the animals' fitness (Beilharz et al., 1993). Energy needed for chewing reduces the amount of metabolizable energy available for production (Susenbeth et al., 1998) and increased time spent on rumination also necessarily decreases time spent on other activities (Van Soest, 1994). Thus, for animals being developed in nutrient scarce environments, such as the Hereford breed, less rumination would have created opportunities for increased production or, e.g., time for foraging, which could have been beneficial for the fitness of the animal.

The smaller fecal PS in Charolais cows compared with Hereford cows may be associated with the longer rumination time per kg NDFI when corrected for BW by the larger breed. In contrast, no effects of breed or BW on fecal PS were observed in a study by Bae et al. (1983).

Excretion of N and Microbial CP Synthesis

Beef production contributes significantly to N emissions in EU28 (EEA, 2017). Nitrogen intake is considered to be the main driver of N excretion in cattle, especially in urine (Huhtanen et al., 2008). Cows fed RC had 11% higher N intake than cows fed TG, but their urinary excretion of N and urea-N was considerably greater, 71% and 178%, respectively. The rumen is a central source of N losses in ruminants (Tamminga, 1992) and efficient rumen microbial N use requires a balance between the supply of RDP and fermentable substrates, mainly carbohydrates. When roughages of low digestibility are fed, energy might become limiting and excess RDP, not used in microbial CP (**MCP**) synthesis, will be absorbed from the rumen and excreted in urine as urea-N (Nocek and Russell, 1988). Thus, the greater urinary N and, especially, urea-N excretion in cows fed RC compared with TG was most likely a result of the lower OMD and lower concentration of WSC in RC, in addition to the higher N content. These results confirm earlier findings in dry dairy cows, where increased intake of metabolizable energy decreased urinary N excretion (Stergiadis et al., 2015).

The tendency for higher urinary N excretion as a percentage of N intake for Hereford compared with Charolais implies lower utilization of N in the rumen of Hereford. However, this result should be interpreted with caution, as there was no difference in apparent OM digestibility or urinary PD excretion between the breeds.

Cows fed TG and RC had the greatest fecal N output, which could be attributed to the greater intake of N on these diets compared with WCO. A positive linear relationship between N intake and fecal N excretion has previously been reported in beef cows (Bernier et al., 2014). Fecal N is largely composited of indigestible microbial matter, which tends to be in proportion to DMI (Van Soest, 1994). Consequently, the greater DMI of Charolais cows was the probable explanation for their greater fecal N output compared with Hereford cows.

Urinary excretion of PD has been used as an indirect method for estimation of rumen MCP synthesis (Chen and Gomes, 1992). The TG diet stimulated microbial production to a greater extent than the other diets, as indicated by the higher urinary output of PD in cows fed TG. This was most likely related to the greater intake, the higher WSC concentration, and the higher OMD of TG compared with the other diets, which agrees with previous reports of increased urinary excretion of allantoin with higher feeding level and increased intake of digestible OM (Südekum et al., 2006).

The PD excretion per kg digestible OM intake was lower for TG compared with RC and WCO, suggesting a shortage of RDP in TG that might have limited MCP production. The CP concentration of TG was near the recommended 6% to 8% of DM required for proper rumen bacteria function (Mertens, 1994). However, the dietary CP content does not fully reflect the amounts of rumen available N in the diet.

CONCLUSIONS

Late-cut RC and WCO harvested at hard dough stage resulted in lower feed intake and lower apparent digestibility compared with late-cut TG and may, therefore, be suitable alternatives to TG for ad libitum feeding of early pregnant beef cows with modest nutritional demands. The 3 experimental forages, all cut at a late stage of maturity, showed large variations in NDF and iNDF concentrations and in ADL-to-NDF and iNDF-to-ADL ratios. This variation in fiber quality was reflected

in their different effects on forage intake, rumination, apparent digestibility, and fecal PS. Intake appeared mainly to be related to digestibility of NDF, but also to NDF concentration. The study confirmed previous reports of increased rumination time per kg DMI and NDFI with increased dietary concentrations of NDF and iNDF, respectively. The differences in fecal PS and distribution among diets seemed to be partly associated with the dietary iNDF-to-ADL ratio, rumination time, and with NDFI per kg BW. Intake appeared to be proportional to cow BW and not affected by the breed itself. Charolais ruminated longer time per kg NDFI when corrected for BW and had smaller fecal PS than Hereford, but despite this disparity no breed difference in apparent OMD was detected. Feeding RC resulted in the greatest urinary N output, most likely because of a limited supply of rapidly digestible carbohydrates relative to N intake. MCP synthesis was stimulated more by TG than by the other forages.

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