Comparative grazing behavior of lactating Holstein-Friesian, Jersey, and Jersey × Holstein-Friesian dairy cows and its association with intake capacity and production efficiency

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ABSTRACT

The objectives of this study were to investigate differences in grazing behavior among Holstein-Friesian (HF), Jersey (JE), and Jersey × Holstein-Friesian (F₁) cows under an intensive, seasonal, grass-based environment and to determine whether associations exist among grazing behavior, intake capacity, and production efficiency. Data from a total of 108 animals (37 HF, 34 JE, and 37 F₁) were available for analysis. Measurements included milk production, body weight (BW), intake, and grazing behavior. Breed group had a significant effect on all of the production, grass dry matter intake, and efficiency parameters investigated. No differences were observed among the breeds for grazing time, number of grazing bouts, grazing bout duration, and total number of bites. Grazing mastications were higher for the JE cows compared with the HF cows. Grass dry matter intake per bite and rate of intake per minute were higher for the HF cows compared with the JE cows. Large differences between the breeds were apparent when grazing behavior measurements were expressed per unit of BW and per unit of intake. In absolute terms, the HF cows spent more time ruminating and had more mastications during rumination than the JE cows. However, when expressed per unit of BW, ruminating time was greater for the JE cows and they tended to have more ruminating mastications compared with the HF cows. Despite these differences, ruminating time and ruminating mastications per unit of intake were similar for the 2 breeds. For the most part, the F₁ cows tended to be similar to the mid-parent mean, but results showed an increase in biting rate, lower grazing duration per bout, and a tendency to achieve a high intake per bite compared with the average of the parent breeds. The results obtained also indicate that inherent grazing and ruminating differences exist between cows varying in intake capacity and production efficiency.

Cows with higher intake capacities have increased grazing time and rate of intake per unit of BW. Increased production efficiency, on the other hand, appears to be aided, in particular by improvements in mastication behavior during grazing.

Key words: grazing behavior, production efficiency, Jersey, crossbreeding

INTRODUCTION

Successful grazing systems require dairy cows that are adapted to achieving large intakes of high-quality grass and efficiently converting the feed to high-value milk solids (MS; fat plus protein yield). The ideal cow should also be capable of maintaining body condition and calving in a timely fashion over multiple lactations to best take advantage of a predominantly grass-based diet (Buckley et al., 2005). With its small size and large intake capacity (Prendiville et al., 2009), the Jersey (JE) represents the extreme in dairy type. Cull cow value, male calf value, and perhaps reproductive efficiency aside, the JE closely resembles the ideal cow for intensive grazing systems. Jersey cows are capable of producing higher yields of MS per unit of area (Penno, 1998), achieve higher intakes per unit of BW (Grainger and Goddard, 2007; Prendiville et al., 2009), and require less energy and feed input per unit of MS produced (Grainger and Goddard, 2007; Prendiville et al., 2009) compared with Friesian or Holstein-Friesian (HF) cows.

Apart from environmental, plant, and management factors (Dillon, 2005), milk production from pasture is limited by the ability of the grazing animal to consume sufficient quantities of herbage (Stakelum and Dillon, 2003). Herbage intake is determined by the combination of time spent grazing, rate of biting, and DMI per bite (Spedding et al., 1966). Diet digestibility is expected to be influenced by variation in ruminating time (Phillips and Hecheimi, 1989). Differences in grazing behavior may indicate suitability or affinity to specialized grazing systems. Indeed, McCarthy et al. (2006) postulated that differences in grazing behavioral

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attributes could be used as traits to refine breeding programs for pasture-based systems.

Grazing behavior differences have been previously observed among strains within the HF breed. O'Connell et al. (2000) reported that HF cows of high production potential had similar grazing time but more grazing bouts of shorter duration and higher biting rates, and spent a greater proportion of time ruminating compared with HF cows of lesser production potential. McCarthy et al. (2006) showed that cows selected under an intensive grazing environment (New Zealand Friesian) spent longer grazing but had lower biting rates compared with HF cows. Laborde et al. (1998) investigated differences in grazing behavior between heavy and light HF cows and reported no difference in grazing time but higher biting rates and lower bite size for the lighter cows. Furthermore, both Bargo et al. (2002) and McCarthy et al. (2006) provided evidence that increased biting rate was associated with increased milk yield. Few studies have compared eating behavior of HF cows with that of JE cows. Those that have are based on TMR diets and involve very small numbers of animals (Welch et al., 1970; Aikman et al., 2008). No previous study has compared the grazing behavior (at pasture) of HF cows with JE or JE $\times$ HF (F_1) cows. Hence, the objective of this study was to investigate whether grazing behavior differences exist among HF, JE, and F_1 cows in an intensive, seasonal, grass-based environment. Also of interest was the extent to which grazing behavior is associated with variations in intake capacity and production efficiency.

MATERIALS AND METHODS

The experiment was conducted at Moorepark Dairy Production Research Centre (Fermoy, Co. Cork, Ireland) on the Ballydague research farm (52°8'N 8°26'W). The experimental area was a permanent grassland site consisting of a sward with almost 100% perennial ryegrass (*Lolium perenne*). This study formed part of a longer term study designed to evaluate the performance of the 3 breed groups on pasture-based production systems. A more in-depth description of the breed groups, experimental design, grazing management, sward composition, and intake measurements has been reported by Prendiville et al. (2009); therefore only a brief description is provided here.

Experimental Animals and Grazing Management

Three breed groups were compared: HF, JE, and F_1 . A total of 108 animals were available for the study: 37 HF, 34 JE, and 37 F_1 cows. Sixteen, 10, and 9 cows were in parity 1 in the HF, JE, and F_1 groups, respectively; the remaining cows were in parity 2. Mean calv-

ing date was February 17 (± 21 d), February 21 (± 23 d), and February 15 (± 26 d) for the HF, JE, and F_1 cows, respectively. The HF cows were sired by 13 sires predominately of North American HF genetics. The JE cows were sired by 13 sires (8 of New Zealand and 5 of Danish origin). The F_1 cows were generated by mating JE bulls ($n = 6$) to HF cows.

Cows were milked twice daily throughout the year at approximately 0700 and 1545 h. Animals were turned out to pasture from early February until mid-November and were housed for the remainder of the year. Animals grazed as a single herd and operated on a rotational grazing system as outlined by Dillon et al. (1995). Grazed grass was the sole diet of the cows during the experimental period. Fresh grass was allocated to the cows each morning with calcined magnesite (Nutribio, Cork, Ireland) dusted on the paddocks during critical periods (February–May and September–November) to prevent magnesium deficiency.

Cow Performance Data

Milk yield was recorded daily using electronic milk meters (Dairymaster, Causeway, Co. Kerry, Ireland), with milk constituents determined from successive a.m. and p.m. milk samples taken weekly using a Milkoscan 203 (Foss Electric, Hillerød, Denmark). Solids-corrected milk yield (kilograms) was calculated as described by Tyrrell and Reid (1965). Body weight was recorded weekly using a calibrated weighing scale (Dairymaster, Causeway, Co. Kerry, Ireland). Body condition score was assessed by the same evaluator every 3 to 4 wk on a scale of 1 to 5 (1 being extremely thin and 5 being extremely fat) with increments of 0.25, similar to that described by Lowman et al. (1976).

Grass DMI and Feed Efficiency

Grass DMI (GDMI) was estimated for each cow on 4 occasions during lactation using the n-alkane technique (Mayes et al., 1986) as modified by Dillon and Stake-lum (1989): early June, mid-July, early September, and early October; these estimates provided a total of 430 records. The estimates on these 4 occasions were (DIM $\pm$ SD) 108 ± 19.2 , 149 ± 20.4 , 198 ± 21.0 , and 233 ± 20.4 , respectively. One measure of intake capacity (GDMI/100 kg of BW) and 2 measures of production and feed efficiency (MS/100 kg of BW and MS/kg of GDMI) were investigated; see Prendiville et al. (2009) for details of calculations.

Grazing Behavior

Grazing behavior data were recorded on 2 occasions during lactation: from June 12 to July 18 (period 1) and

from September 18 to November 7 (period 2). These recordings corresponded to 133 ± 24 and 240 ± 25 DIM. After the a.m. milking, cows were fitted with Institute of Grassland and Environmental Research headset behavior recorders (Rutter et al., 1997) as described by Kennedy et al. (2009). Measurements were carried out over a 24-h period because of the diurnal patterns of grazing behavior (Champion et al., 1994). Measurements were conducted on up to 12 cows per day during each measurement period. In preparation for the fitting of the headset behavior recorders, head collars (minus the recording apparatus) were fitted to each cow 24-h previously. A total of 154 and 185 attempts yielded 100 (32 HF, 33 JE, and 35 F₁ cows) and 101 (37 HF, 32 JE, and 32 F₁ cows) records from grazing behavior measurement periods 1 and 2, respectively. The majority (77%) of the failed attempts were caused by problems and breakages associated with the transponders (nosebands located under the jaw of the cow). Other sources of trouble included battery failure during the required 24-h period (12%) and occasional difficulties associated with the downloading of the recorded data from the storage device (memory card; 11%). Outliers were defined as those that were 2 interquartile ranges above or below the 75th and 25th percentiles, respectively, for individual part-day measurements; behavior data pertaining to 2 HF cows were removed for this reason.

The data collected were subsequently discerned using Graze analysis software (Rutter, 2000). Behavior measurements included grazing and ruminating time (minutes/day), number of grazing and ruminating bouts, number of grazing bites, number of grazing and ruminating mastications, and number of ruminating boli. Bite rate, grazing and ruminating bout duration, rate of grazing mastications, intake per bite, rate of intake per minute, rate of ruminating mastications per minute, and bolus size were also extrapolated using the aforementioned grazing behavior and intake data.

Sward Measurements and Chemical Analysis

Sward measurements and chemical analyses were as outlined by Prendiville et al. (2009). Briefly, 40 pre- and postgrazing sward heights were measured on all paddocks using a rising plate meter (Urban and Caudal, 1990) for the duration of the grazing season. Pregrazing herbage yields (>4 cm) were determined for each paddock based on 5 quadrats (0.25×0.25 m) of grass cut using electronic shears as described by O'Donovan et al. (2002). Pregrazing herbage yields (>4 cm) were targeted between 1,400 and 1,600 kg of DM/ha.

Statistical Analysis

Analysis of variance was undertaken using PROC MIXED of SAS (version 9.1; SAS Institute Inc., Cary, NC). The linear model included the fixed effects of breed group (HF, JE, and F₁), parity, and measurement period ($n = 4$ for the animal performance and efficiency measurements; $n = 2$ for the grazing behavior data). Calving day of year was included as a continuous covariate. Contrast statements in PROC MIXED were used to determine whether differences existed between the HF and JE breeds. Similarly, the F₁ breed was compared with the performance of the mid-parent (breed) mean, simultaneously providing an estimate of hybrid vigor between the 2 breeds.

Associations between intake capacity and efficiency variables with grazing behavior outcomes across breed group were investigated using partial Pearson correlations. For the purpose of this analysis, the mean GDMI and efficiencies were calculated for intake measurement 1 and 2, designated for this analysis as measurement period 1 (corresponding to grazing behavior recording period 1), and intake measurements 3 and 4, designated as measurement period 2 (corresponding to grazing behavior recording period 2). This analysis was adjusted for the effect of breed group, parity, and calving day of year using the PROC CORR procedure of SAS. This analysis had the advantage of making use of the full range of data within the data set.

RESULTS

Grazing Measurements and Nutrient Composition

Pre- and postgrazing sward surface heights were similar in both measurement periods, but pregrazing herbage yield was higher in the second period (Table 1). The nutrient composition of the herbage offered was high in both periods.

Milk Production and Milk Composition

Daily yield of milk was greater ($P < 0.001$) for the HF cows compared with the JE cows (Table 2). Milk fat and protein contents were higher ($P < 0.001$) for the JE cows compared with the HF cows (+1.40 and +0.62%, respectively). Consequently, MS yield was similar for the 2 groups. The HF cows produced more ($P < 0.05$) SCM compared with the JE cows (15.8 and 14.7 kg, respectively). Milk lactose content was not different between the 2 breed groups.

The F₁ cows had a higher yield of milk ($P < 0.05$), produced more MS ($P < 0.001$), had a greater lactose

Table 1. Pre- and postgrazing sward surface heights, pregrazing herbage yield, and chemical composition of grass offered to cows during the measurement periods

Item	June 12 to July 18		September 18 to November 7	
	Mean	SD	Mean	SD
Pregrazing sward surface height (cm)	11.4	1.7	10.9	2.0
Postgrazing sward surface height (cm)	4.9	0.6	5.3	1.0
Pregrazing grass yield (kg of DM/ha)	1,213	216	1,657	486
CP (g/kg of DM)	230	20	232	34
ADF (g/kg of DM)	258	12	282	12
OM digestibility (g/kg of OM)	745	40	751	32
NDF (g/kg of DM)	470	21	460	9

content ($P < 0.001$), and had a higher yield of SCM ($P < 0.001$) compared with the mid-parent mean. Estimates of hybrid vigor were 0.83 kg/d, 0.11 kg/d, 0.10%, and 1.37 kg/d for milk yield, MS yield, lactose content, and SCM, respectively. Milk fat and protein values were similar to the mid-parent mean.

BW and BCS

The BW of the JE cows (373 kg) was 74% that of the HF cows (Table 2). Mean BCS was greater ($P < 0.01$) for the JE cows than the HF cows (2.91 and 2.75, respectively). The F_1 cows had a greater BW and BCS compared with the mid-parent mean. This corresponded to hybrid vigor estimates of +14 kg (+3.1%) and +0.17 (+5.7%) for BW and BCS, respectively.

Intake and Efficiency

The HF cows had a higher GDMI than the JE cows (16.7 vs. 14.6 kg/d), but estimated GDMI per 100 kg of

BW was greater for the JE cows compared with the HF cows (4.03 and 3.40 kg/100 kg of BW, respectively). Yield of MS per 100 kg of BW was 32% greater for the JE cows compared with the HF cows (0.33 and 0.25 kg/100 kg of BW, respectively). The JE cows also produced more MS per kg of GDMI compared with the HF cows ($P < 0.001$).

Daily GDMI was 0.25 kg greater ($P < 0.01$) for the F_1 cows compared with the breed parent mean, but GDMI per 100 kg of BW was similar. Though numerically higher, production of MS per 100 kg of BW was not different between the F_1 cows and the mid-parent breed mean. The F_1 cows at 0.082 kg of MS/kg of GDMI produced an additional 0.005 kg of MS/kg of GDMI above the average of the pure lines ($P < 0.01$).

Variation in Grazing Behavior

Recorded Measurements. Grazing time, number of grazing bouts, grazing bout duration, total number of bites per day, and bite rate were similar for the HF

Table 2. Effect of dairy cow breed group¹ on mean daily milk production performance, BW, BCS, grass intake, grass intake capacity, and production efficiency measures

Item	Breed group			HF vs. JE		F ₁ vs. parent mean	
	HF	JE	F ₁	SEM	P-value	SEM	P-value
Milk yield (kg/d)	16.9	12.8	15.7	0.43	<0.001	0.37	<0.05
Fat (%)	4.00	5.40	4.79	0.11	<0.001	0.09	NS ²
Protein (%)	3.56	4.18	3.93	0.05	<0.001	0.04	NS
Lactose (%)	4.45	4.48	4.56	0.023	NS	0.025	<0.001
Fat yield (kg/d)	0.66	0.68	0.74	0.021	NS	0.018	<0.001
Protein yield (kg/d)	0.59	0.52	0.61	0.016	<0.001	0.014	<0.001
Yield of milk solids (kg/d)	1.26	1.22	1.35	0.03	NS	0.03	<0.001
SCM (kg/d)	15.8	14.7	16.6	0.42	<0.05	0.63	<0.001
BW (kg)	503	373	452	6.6	<0.001	5.7	<0.05
BCS	2.75	2.91	3.00	0.05	<0.01	0.04	<0.001
GDMI ³ (kg/d)	16.7	14.6	15.9	0.35	<0.001	0.31	<0.01
GDMI (kg/100 kg of BW)	3.40	4.03	3.63	0.07	<0.001	0.06	NS
Milk solids (kg/100 kg of BW)	0.25	0.33	0.30	0.008	<0.001	0.006	NS
Milk solids (kg/kg of GDMI)	0.074	0.081	0.082	0.0016	<0.001	0.0014	<0.01

¹HF = Holstein-Friesian; JE = Jersey; F₁ = Jersey × Holstein-Friesian.

²NS = $P > 0.05$.

³GDMI = grass DMI.

Table 3. Grazing behavior of 3 dairy cow breed groups¹

Item	Breed group			HF vs. JE		F ₁ vs. parent mean	
	HF	JE	F ₁	SEM	P-value	SEM	P-value
Grazing time (min/d)	646	637	662	20.1	NS ²	17.5	NS
Grazing bouts (n/d)	10	8.9	10.2	0.81	NS	0.58	NS
Grazing bout duration (min/bout)	79.5	83.9	71.7	4.99	NS	4.35	<0.05
Total bites (n/d)	40,672	39,433	39,859	1,236.7	NS	1,078.0	NS
Bite rate (n of bites/min)	57	59	60	1.10	NS	0.96	<0.05
Grazing mastications (n/d)	3,963	4,785	4,252	384.0	<0.05	335.1	NS
Grazing mastications rate (n of mastications/min)	6.3	7.5	6.6	0.61	<0.05	0.53	NS
GDMI ³ (g/bite)	0.42	0.38	0.42	0.017	<0.05	0.015	NS
Rate of GDMI (g/min)	26.5	23.3	25.1	0.97	<0.01	0.85	0.063
Per 100 kg of BW							
Grazing time (min)	129	171	149	64.4	<0.001	45.5	NS
Total bites (n/day)	8,186	10,543	8,841	296.3	<0.001	258.1	<0.05
Bite rate (n of bites/min)	11.5	15.8	13.4	0.36	<0.001	0.32	NS
Mastications (n/d)	796	1,292	954	92.9	<0.001	81.1	NS
GDMI (g/bite)	0.083	0.102	0.093	0.0039	<0.001	0.0034	NS
Rate of GDMI (g/min)	5.3	6.2	5.6	0.21	<0.001	0.18	NS
Per kg of GDMI							
Grazing time (min)	39.3	44	41.9	1.51	<0.01	1.31	NS
Total bites (n/d)	2,480	2,714	2,517	92.3	<0.01	80.3	NS
Bite rate (n of bites/min)	3.4	4.0	3.8	0.11	<0.001	0.10	NS
Grazing mastications (n)	241	329	273	25.9	<0.01	22.6	NS

¹HF = Holstein-Friesian; JE = Jersey; F₁ = Jersey × Holstein-Friesian.

²NS = $P > 0.05$.

³GDMI = grass DMI.

and JE cows (Table 3). The number of grazing mastications was higher ($P < 0.05$) for the JE cows compared with the HF cows. The rate of grazing mastications per minute was also greater for the JE cows compared with the HF cows. The HF cows had a higher ($P < 0.05$) grass intake per bite (0.42 vs. 0.38 g) and a higher rate of GDMI ($P < 0.01$) compared with the JE cows. The F₁ cows had a shorter grazing bout duration ($P < 0.05$), higher bite rate ($P < 0.05$), and tended to have a higher rate of GDMI ($P = 0.063$) compared with the mean of the parent breeds.

Grazing Behavior Expressed Per 100 kg of BW. When expressed per unit of BW, large ($P < 0.001$) differences in grazing behavior were evident. The JE cows displayed a longer total grazing time (171 vs. 129 min/d), more bites per day, more bites per minute (15.8 vs. 11.5), a higher rate of GDMI (6.2 vs. 5.3 g/min), and a greater bite size (0.102 vs. 0.083 g/bite) compared with the HF cows. When expressed per unit of BW, the F₁ cows had fewer bites per day ($P < 0.05$) compared with the mid-parent breed mean (8,841 and 9,364 bites/d, respectively).

Grazing Behavior Expressed Per kg of GDMI. The HF cows required less time to ingest 1 kg of GDMI compared with the JE cows (39.3 and 44.0 min/kg, respectively). The JE cows had more bites ($P < 0.01$) and exhibited 36.5% more grazing mastications per unit of intake compared with the HF cows. The F₁ cows were

not different from the mid-parent mean for any grazing behavior measures expressed per unit of intake.

Variation in Ruminating Behavior

Recorded Measurements. The HF cows spent more time ruminating ($P < 0.01$) compared with the JE cows (426 vs. 371 min/d, respectively), but the number of ruminating bouts per day was similar for the 2 breeds (Table 4). Consequently, ruminating bout duration was longer ($P < 0.001$) for the HF cows compared with the JE cows. The total number of ruminating mastications and the rate of ruminating mastications per minute were both greater for the HF cows compared with the JE cows. The JE cows had a higher ($P < 0.05$) number of ruminating boli but had less ($P < 0.001$) ruminating time per bolus than the HF cows (0.91 and 1.39 min/bolus, respectively). The size of the bolus regurgitated by the JE cows was 70% that of the HF cows ($P < 0.01$). The number of ruminating boli per bout and the number of mastications per bolus were similar for the 2 breed groups. Ruminating measurements of the F₁ cows were not different from the mid-parent breed mean.

Ruminating Behavior Expressed Per 100 kg of BW and Per kg of GDMI. Ruminating time per 100 kg of BW was 13.7 min/d longer for the JE cows compared with the HF cows ($P < 0.01$). The total number of ruminating mastications tended to be higher for the

Table 4. Ruminating behavior of 3 dairy cow breed groups¹

Item ²	Breed group			HF vs. JE		F ₁ vs. parent mean	
	HF	JE	F ₁	SEM	P-value	SEM	P-value
Ruminating time (min/d)	426	371	383	22.1	<0.01	19.2	NS ²
Ruminating bouts (n/d)	17.4	14.5	12.8	4.92	NS	4.29	NS
Ruminating bout duration (min/bout)	36.8	26.1	32.0	2.16	<0.001	1.88	NS
Ruminating mastications (n/d)	25,782	21,758	23,425	1,458.2	<0.01	1,271	NS
Ruminating mastication rate (n of mastications/min)	62.6	59.6	61.5	1.46	<0.05	1.27	NS
Ruminating boli (n/d)	357	422	352	26.0	<0.05	22.6	NS
Bolus size (g)	57.5	40.7	57.4	5.22	<0.01	4.56	NS
Ruminating time (min/bolus)	1.39	0.91	1.15	0.127	<0.001	0.109	NS
Ruminating boli (n/ruminating bout)	31.7	30.1	29.8	2.26	NS	1.97	NS
Total masticating time (min/d)	418	363	372	22.5	<0.05	19.3	NS
Ruminating mastications (n/bolus)	14.1	12.2	14.8	1.99	NS	1.73	NS
Per 100 kg of BW							
Ruminating time (min)	83.8	97.5	82.8	3.59	<0.01	4.78	NS
Ruminating mastications (n)	5,174	5,847	5,177	343	0.052	294.2	NS
Bolus size (g)	11.7	10.9	12.5	1.29	NS	1.10	NS
Per kg of GDMI ³							
Ruminating time (min)	25.4	24.9	23.6	2.38	NS	1.05	NS
Ruminating mastications (n)	1,571	1,501	1,455	92.6	NS	79.4	NS

¹HF = Holstein-Friesian; JE = Jersey; F₁ = Jersey × Holstein-Friesian.²NS = $P > 0.05$.³GDMI = grass DMI.

JE cows ($P = 0.052$), but no difference in bolus size was observed when expressed per unit of BW. When expressed per 100 kg of BW, ruminating measurements of the F₁ cows were similar to the mid-parent mean. When expressed per unit of intake, no differences were apparent between the HF and JE cows or between the F₁ cows and the parental mean.

Associations Between Intake Capacity, Production Efficiency, and Grazing Behavior

Grazing time was not found to be associated with either intake capacity (GDMI/100 kg of BW) or any of the efficiency parameters investigated (Table 5). Negative correlations were evident between the number of grazing bouts and both GDMI/100 kg of BW ($P < 0.05$) and MS/100 kg of BW ($P < 0.05$). The relationship between the number of grazing bouts and MS/GDMI proved nonsignificant. No associations were found between grazing bout duration, total number of bites, and bite rate with any of the intake capacity or efficiency measures investigated. Intake per bite was positively associated with intake capacity ($P < 0.05$) and tended to be negatively correlated with MS/GDMI ($P = 0.052$). A positive relationship was also evident between rate of intake (GDMI/minute) and intake capacity (GDMI/100 kg of BW; $P < 0.05$). No association was apparent between GDMI/minute and the efficiency measures investigated. A negative correlation was observed between grazing time/GDMI and GDMI/100 kg of BW ($P < 0.05$). No relationships were found be-

tween grazing time/GDMI and the efficiency measures. Grazing time/100 kg of BW was positively correlated with GDMI/100 kg of BW ($P < 0.001$), MS/100 kg of BW ($P < 0.001$), and MS/GDMI ($P < 0.05$). Cows that spent more time masticating the herbage had a higher output of MS/100 kg of BW ($P < 0.05$) and higher MS yield per GDMI ($P < 0.05$). The number of grazing mastications/GDMI was positively associated with MS/100 kg of BW ($P < 0.05$) and MS/GDMI ($P < 0.01$). Similarly, rate of grazing mastications were positively associated with output per 100 kg of BW ($P < 0.05$) and output per unit of GDMI ($P < 0.05$).

Associations Between Intake Capacity, Production Efficiency, and Ruminating Behavior

No association was observed between ruminating time and the number of ruminating bouts with intake capacity (GDMI/100 kg of BW) or either of the efficiency measures investigated (Table 6). Ruminating bout duration was weakly negatively correlated with GDMI/100 kg of BW ($P < 0.05$). No relationship was evident between the efficiency measures and ruminating bout duration. Ruminating time/100 kg of BW was positively correlated with both GDMI/100 kg of BW ($P < 0.001$) and MS/100 kg of BW ($P < 0.001$). Ruminating time/GDMI, ruminating mastications, and ruminating mastications/minute were not correlated with any of the intake capacity or efficiency measures investigated. Cows that had increased ruminating mastications/100 kg of BW had a higher intake capacity

Table 5. Correlations (*P*-values in parentheses) between intake capacity and production efficiency measures with grazing behavior across 3 dairy cow breed groups

Item	GDMI ¹ (kg/100 kg of BW)	MS ² (kg/100 kg of BW)	MS (kg/kg of GDMI)
Grazing time (min/d)	-0.13 (NS ³)	-0.13 (NS)	-0.04 (NS)
Grazing bouts (n/d)	-0.24 (<0.05)	-0.24 (<0.05)	-0.12 (NS)
Grazing bout duration (min/bout)	0.11 (NS)	0.12 (NS)	0.07 (NS)
Total bites (n/d)	-0.09 (NS)	-0.10 (NS)	-0.05 (NS)
Bite rate (n of bites/min)	-0.05 (NS)	-0.04 (NS)	0.01 (NS)
GDMI (g/bite)	0.14 (<0.05)	0.02 (NS)	-0.13 (0.052)
Rate of GDMI (g/min)	0.17 (<0.05)	0.04 (NS)	-0.14 (NS)
Grazing time (min/kg of GDMI)	-0.22 (<0.01)	-0.08 (NS)	0.14 (NS)
Grazing time (min/100 kg of BW)	0.41 (<0.001)	0.39 (<0.001)	0.14 (<0.05)
Grazing mastications (n/d)	0.12 (NS)	0.22 (<0.05)	0.22 (<0.05)
Grazing mastications (n/kg of GDMI)	0.07 (NS)	0.22 (<0.05)	0.28 (<0.01)
Grazing mastication rate (n of mastications/min)	0.14 (NS)	0.24 (<0.05)	0.23 (<0.05)

¹GDMI = grass DMI.²MS = milk solids.³NS = *P* > 0.05.

(*P* < 0.001) and produced more MS/100 kg of BW (*P* < 0.001). Negative correlations were apparent between bolus size and GDMI/100 kg of BW (*P* < 0.05) and MS/100 kg of BW (*P* < 0.05), but bolus size/100 kg of BW was not associated with MS/GDMI. A positive relationship was also evident between ruminating boli and GDMI/100 kg of BW (*P* < 0.001) and MS/100 kg of BW (*P* < 0.01). Similarly, cows that regurgitated more boli per ruminating bout had a greater output of MS/100 kg of BW and MS/GDMI. Ruminating mastications/bolus were negatively correlated with GDMI/100 kg of BW (*P* < 0.01). However, no relationships were evident between ruminating mastications per bolus and the efficiency measures investigated. Ruminating time/bolus was not associated with intake capacity or any of the efficiency parameters investigated.

DISCUSSION

Although JE cows, or perhaps more particularly F₁ cows, have previously been noted by many authors as being a genotype particularly well suited to grazing systems (Penno, 1998; Lopez-Villalobos et al., 2000; Buckley et al., 2005), no study has been conducted to evaluate the grazing mechanisms of the JE or JE crossbred cow until now. Indeed, few studies have truly examined differences in grazing and ruminating behavior between breeds and strains of dairy cow. In virtually all publications where grazing and feeding behavior forms part of the study, reference is made to the fact that successful grazing is governed by the time spent grazing, the bite rate, and herbage intake per bite (Spedding et al., 1966; Holmes, 1989; McCarthy et al.,

Table 6. Correlations (*P*-values in parentheses) between intake capacity and production efficiency measures with ruminating behavior variables across 3 dairy cow breed groups

Item	GDMI ¹ (kg/100 kg of BW)	MS ² (kg/100 kg of BW)	MS (kg/kg of GDMI)
Ruminating time (min/d)	0.02 (NS ³)	0.05 (NS)	-0.09 (NS)
Ruminating bouts (n/d)	-0.15 (NS)	-0.15 (NS)	-0.09 (NS)
Ruminating bout duration (min/bout)	-0.17 (<0.05)	-0.11 (NS)	0.05 (NS)
Ruminating time (min/100 kg BW)	0.37 (<0.001)	0.29 (<0.001)	0.02 (NS)
Ruminating time (min/kg of GDMI)	-0.06 (NS)	-0.04 (NS)	0.02 (NS)
Ruminating mastications (n/d)	0.03 (NS)	-0.03 (NS)	-0.07 (NS)
Ruminating mastication rate (n of mastications/min)	-0.02 (NS)	-0.03 (NS)	-0.03 (NS)
Ruminating mastications (n/100 kg of BW)	0.35 (<0.001)	0.28 (<0.001)	0.03 (NS)
Ruminating mastications (n/kg of GDMI)	-0.06 (NS)	-0.03 (NS)	0.02 (NS)
Total mastications (n/min)	0.02 (NS)	-0.05 (NS)	-0.09 (NS)
Bolus size (g)	-0.22 (<0.05)	-0.24 (<0.05)	-0.13 (NS)
Bolus size (g/100 kg of BW)	-0.05 (NS)	-0.07 (NS)	-0.06 (NS)
Ruminating boli (n/d)	0.34 (<0.001)	0.28 (<0.01)	0.05 (NS)
Boli (n/ruminating bout)	0.11 (NS)	0.17 (<0.05)	0.16 (<0.05)
Ruminating mastications (n/bolus)	-0.19 (<0.01)	-0.12 (NS)	0.04 (NS)
Ruminating time (min/bolus)	-0.02 (NS)	-0.03 (NS)	-0.03 (NS)

¹GDMI = grass DMI.²MS = milk solids.³NS = *P* > 0.05.

2006). Broadly, this statement is not untrue. However, the details by which grass intake and intake capacity differ, and consequently feed and production efficiency differences ultimately manifest, are often overlooked.

The observed differences in production, BW, BCS, intake, and efficiency performance in the current study have been presented as background information. The findings have been discussed, in detail, by Prendiville et al. (2009) and so will not be repeated here. In the current study, all animals were grazed as part of a single herd. According to Oldenbroek and Jansen (1978), pasturing different breeds together has little influence on grazing behavior.

Feeding behavior is inextricably linked to the nature of the feed on offer and the circumstance by which the feed is presented; the obvious extremes being the indoor TMR, where feed is offered simply to be consumed, versus the grazing scenario, where pasture is offered in situ and must be sought out and harvested by the cow. The pasture measurements recorded in this study (pregrazing yield, pre- and postgrazing sward surface heights, chemical composition of the herbage offered) indicate that sufficient quantities of high-quality pasture (O'Donovan et al., 2004) were allocated to the animals over the course of the experiment.

The mean grazing time across the 3 breed groups in the current study was 648 min/d or 10.8 h/d, almost double that observed by Aikman et al. (2008), who studied the feeding behavior of lactating Holstein (H) and JE cows indoors on TMR. The large difference between the studies is likely because of the different diets offered to the cows (TMR vs. grass). Mean grazing time in the current study was also slightly higher than that reported by both Rossi et al. (2005) and McCarthy et al. (2006), who had mean grazing times of 8.4 h/d and 9.8 h/d, respectively. In the study of Rossi et al. (2005), cows were offered 2 levels of herbage mass, 2,100 and 2,800 kg of DM/ha, with grazing times of 9.2 and 7.7 h/d, respectively. McCarthy et al. (2006) reported pre- and postgrazing sward surface heights of 22.8 and 7.9 cm, respectively. In both studies, higher pregrazing yields and sward heights were available compared with those in the current study, thus enabling larger bite sizes and, hence, shorter grazing times (Casey and Brereton, 1999). In the study of McCarthy et al. (2006), concentrate supplementation was also offered to some of the treatments. Previous research indicates that concentrate supplementation results in reduced grazing times (O'Connell et al., 2000; Bargo et al., 2003).

Breed Differences

Despite a relatively large difference in GDMI between the HF and JE breeds in the current study, no

difference in absolute grazing pattern (total grazing time, number of grazing bouts, and grazing bout duration) was observed. This is consistent with the findings of Aikman et al. (2008), who reported similar eating times for lactating H and JE dairy cows (360 and 382 min/d, respectively) offered a TMR. Aikman et al. (2008) also reported similarities between H and JE cows for the number of eating bouts and eating bout duration. Furthermore, in the current study, no difference in the number of grazing bites or the rate of biting was observed. However, when the data are viewed in more detail, it becomes apparent that fundamental differences in grazing behavior do exist between the breeds. A similar grazing time and number of bites yet lower GDMI indicates a lower rate of consumption for the JE cows compared with the HF cows. This can be explained by the smaller physical size of the JE cows and is confirmed by a longer grazing time per 100 kg of BW, lower GDMI per minute, and lower GDMI per bite. Rook (2000) emphasized that bite mass is affected by the constraints of the grazing animal's anatomy, including both mouth and body size. Nevertheless, on a per unit of BW basis, the JE cows in the current study were observed to exhibit a more aggressive grazing aptitude compared with the HF cows, denoted by large differences in bite rate, intake rate, and increased grazing time. The JE breed was also observed to have a greater number of grazing mastications and a faster rate of mastication compared with the HF breed, which could also be because of the smaller physical size of the JE breed. These differences between breeds become more apparent when expressed on a per unit of intake basis. The increase in grazing mastications per kg of GDMI by the JE cows agrees with the fact that the breed also exhibited an increased grazing time per kg of GDMI. Total masticating time did not differ between the breeds, however. Bae et al. (1983) reported higher total chewing time for animals with a lower metabolic BW, but concluded that larger animals had greater chewing efficiency (defined as less chewing time per cell wall constituent intake).

Rumination is defined as the regurgitation of fibrous ingesta from the rumen to the mouth, remastication, and reinsalivation, followed by swallowing and returning the material to the rumen (Welch, 1982). In the current study, absolute ruminating time was higher for the HF cows compared with the JE cows (mean ruminating bout duration was approximately 10 min longer for the HF cows), as was the number of ruminating mastications per day. This is consistent with the findings of Aikman et al. (2008), who reported that lactating H cows spent more time ruminating (623 min/d) than JE cows (538 min/d). The large difference in ruminating time between the 2 studies is likely because of the

different feeds offered to the cows. The diet offered by Aikman et al. (2008) was a TMR containing both grass silage and corn silage, whereas high-quality pasture was offered in the current study. Although the NDF content of the pasture was higher, it is likely that the physically effective NDF of the TMR diet was greater because of the highly fermentable nature of the fiber in fresh, high-quality pasture. This would elicit more chewing in animals on that diet (Mertens, 1997).

The limitation of physical size also appeared to dictate the pattern of bolus movement during the ruminating process, bearing in mind that intake per unit of BW was greater for the JE cows. Bolus size was smaller with the JE cows (on average 70% that of the HF cows). However, when expressed relative to body mass, there was no difference between the breeds. The number of boli per ruminating bout was not different between the breeds despite the 10-min difference in ruminating bout duration. Expressed in another way, the total number of ruminating boli and rate of bolus turnover was greater for the JE cows, who regurgitated a new bolus every 55 s, compared with every 83 s for the HF cows. Hence, the JE cows spent less time ruminating each bolus. However, the number of mastications per bolus was similar for both HF and JE cows. In contrast, Aikman et al. (2008) reported similar ruminating boli for the H and JE cows. In that study, however, intake per unit of BW did not differ between the breeds, a finding that is atypical of studies comparing the intake capacity of HF and JE cows (Grainger and Goddard, 2007). Although both the JE and H cows in the study of Aikman et al. (2008) were larger than the animals in the current study, the relative difference between the breeds was similar. Hence, differences in size would not explain this inconsistency between the studies.

F₁ and Mid-Parent Mean

For the most part, the results of the current study indicate that grazing and ruminating behavior of F_1 cows reflect the average of the 2 parent breeds. Evidence of improved grazing efficiency, however, was observed for the crossbred over and above the parent breeds for increased bite rate, increased grass intake per minute, and an associated reduction in grazing bout duration, thus adding credence to the perception that F_1 cows are well adapted to intensive grazing environments because of the advantages conferred by hybrid vigor.

Intake Capacity

Cows capable of achieving high intakes of grazed grass per unit of BW (high intake capacity) are desirable for intensive grazing systems (Buckley et al., 2005). It is

clear from the results obtained that inherent grazing and ruminating differences do exist between cows capable of achieving high and low grass intakes per unit size. Cows with high intake capacity tend to be smaller than contemporaries with low intake capacity, but tend to have higher intakes and higher output per unit of BW (Prendiville et al., 2009). Based on the current study, they do not graze for longer per se, but do graze for longer on a per unit of BW basis. They would also appear to be more efficient grazers from the perspective of intake per bite, intake per unit of time, and time spent grazing per unit of intake. Perhaps surprising is the fact that no association was obtained between any of the mastication efficiency traits (i.e., traits that might be expected to reduce particle size, increase rate of passage, and so on) and intake capacity (Welch and Smith, 1970). This suggests that cows with higher intake capacities may simply have a greater rumen capacity per unit of BW. Evidence of this effect has been presented previously. Jersey cows were shown to have a greater rumen–reticulum mass and volume compared with H cows (Smith and Baldwin, 1974) and German Black and White cows (Nagel and Piatkowski, 1988) on a per liveweight and a per metabolic liveweight basis.

Similarly, no association was observed between absolute ruminating time or ruminating time per unit of GDMI and intake capacity. In line with differences observed between the HF and JE breeds, cows with high intake capacities did, however, exhibit longer ruminating times and more ruminating mastications per unit of BW, a consequence of higher intake per unit of BW. They also tended to have shorter ruminating bouts and more but smaller ruminating boli, agreeing with the previous finding that high intake capacity tends to be characterized by a smaller physical size.

The ruminating data in the current study suggest a due process with regard to the HF and JE cows as far as rumination is concerned (i.e., similar ruminating time per unit of intake). In the current study, time spent ruminating per kg of GDMI averaged 24.8 min/kg across the 3 breed groups, lower than that obtained by Aikman et al. (2008), who obtained values of 28.3 and 36.6 min/kg for H and JE cows, respectively. However, as discussed previously, the difference between the 2 studies is likely caused by the different diets offered in terms of physically effective NDF.

Production Efficiency

Grainger and Goddard (2007) reviewed data on the intake and production of JE and HF cows. They showed that, in most of the studies reviewed, JE cows produced more MS per kg of DMI than their HF counterparts. More recently, Prendiville et al. (2009) reported that

JE cows produced more MS per unit of BW and per unit of intake. Ingvarsen and Weisberg (1993) and Aikman et al. (2008) demonstrated a higher rate of passage in JE cows compared with Friesian and H cows, respectively. Broadly, in the current study, cows that expressed a high output of MS per unit of BW displayed grazing and ruminating behavior characteristics similar to cows capable of high intake capacity concurring with the positive association between the 2 previously identified by Prendiville et al. (2009). The association between grazing mastications per minute and MS per kg of GDMI was significant. It is logical to assume that increased mastications per unit of intake could facilitate increased digestibility via buffered rumen pH mediated through increased saliva production (Wales et al., 2004). Increased mastications per unit of intake may also change particle size. Hristov et al. (2003) demonstrated that ruminal particles with high functional specific gravity had a higher passage rate in the digestive tract than particles with low functional specific gravity, and that particle size and specific gravity are interrelated (Siciliano-Jones and Murphy, 1991). This hypothesis agrees with much of the work carried out in earlier studies. Aikman et al. (2008) considered that particle size reduction was probably more effective in JE cows because of increased chewing time per unit of DM.

CONCLUSIONS

The current study is the first study to provide an insight into the comparative grazing behavior of HF, JE, and F₁ cows under grazing conditions. Ostensibly, the data presented indicates that little difference in grazing behavior was apparent among the breeds. However, when expressed per unit of BW and per unit of intake, notable differences between the breeds became apparent. Evidence presented also suggests that the crossbred cows may in fact display hybrid vigor for some components of grazing efficiency, adding credence to the belief that F₁ cows are well suited to intensive grazing systems. It is clear from the results obtained that inherent grazing and ruminating differences do exist between cows varying in intake capacity and production efficiency. The current findings imply that cows with higher intake capacities simply have a greater rumen capacity per unit of BW (i.e., that intake capacity is not aided by variations in grazing behavior other than increased grazing time and rate of intake per unit of BW). Increased production efficiency, on the other hand, would appear to be aided in particular by improvements in mastication behavior during grazing.

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