Milk production and energy efficiency of Holstein and Jersey-Holstein crossbred dairy cows offered diets containing grass silage

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ABSTRACT

Eight Holstein and 8 Jersey-Holstein crossbred dairy cows (all primiparous) were used in a repeated 2 (genotype) × 2 (concentrate level) factorial design study involving a total of 4 periods (each of 6-wk duration), designed to examine the effect of cross-breeding on the efficiency of milk production and energy use. The 4 periods began at 5, 11, 27, and 33 wk of lactation, respectively. Animals were offered a completely mixed diet containing grass silage and concentrates, with the level of concentrate in the diet either 30 or 70% of dry matter (DM). During the final 10 d of each period, ration digestibility and energy use was measured, the latter in indirect open-circuit respiration calorimeters. No significant interaction existed between cow genotype and dietary concentrate level for feed intake, milk production, or any of the energy use parameters measured. Across the 2 genotypes, total DM intake, milk yield, and milk protein and lactose concentrations increased with increasing dietary concentrate level. Thus, cows offered the high-concentrate diet had a higher gross energy (GE) intake, and a higher energy output in feces, urine, milk as heat, and a higher metabolizable energy (ME) intake as a proportion of GE intake and as a proportion of digestible energy intake. Across the 2 levels of concentrates, the Jersey-Holstein cows had a significantly higher total DM intake and body condition score, and produced milk with higher fat, protein, and energy concentrations, compared with those of the Holstein cows. In addition, the Jersey-Holstein cows had a significantly higher GE intake and energy output in urine, methane, and milk. However, crossbreeding had no significant effect on energy digestibility or metabolizability, energy partitioning between milk and body tissue, or the efficiency of ME use for lactation. Relating ME intake to milk energy output and heat production indicated that crossbreeding did not influence

ME requirement for maintenance or energy efficiencies. The energy metabolism data were also used to compare energy efficiencies between “early” (data pooled for the first 2 periods) and “late” (data pooled for the second 2 periods) stages of lactation. Stage of lactation had no effect on energy digestibility or metabolizability, whereas increasing stage of lactation increased the rate of energy partitioning into body tissue and reduced the rate of energy partitioning into milk, irrespective of cow genotype. In conclusion, crossbreeding of Holstein dams with Jersey sires had no adverse effects on the overall production efficiency of Holstein dairy cows in terms of milk production, efficiency of ME use for lactation, and energy partitioning between milk and body tissue.

Key words: energy use, Holstein cow, Jersey-Holstein cow, milk production

INTRODUCTION

Historically, selection programs within the Holstein breed have focused on milk production at the expense of functional traits such as fertility, health, and longevity. Although milk yields within the Holstein population have increased, clear evidence exists of declining fertility levels (Lucy, 2001; Pryce et al., 2004; Mackey et al., 2007). In addition, levels of inbreeding within many Holstein populations continue to increase (Hansen, 2000). This decrease in functional traits within the Holstein population has prompted an increased interest in crossbreeding as a means of improving cow fertility, health, and longevity traits. The benefits of crossbreeding include heterosis, and the potential to introduce desirable traits from another breed. Several breeds have been used as sires on Holstein cows within recent crossbreeding programs, including the Scandinavian Red, Montbeliarde, Normande (Heins et al., 2006), and Jersey (Auldist et al., 2007; Prendiville et al., 2010), with clear benefits in terms of milk composition and fertility having been reported. Whereas some studies have reported differences between purebred and crossbred dairy cattle in terms of body tissue reserve, little detailed information is available on the effect of crossbreeding on the efficiency of energy use for lactation.

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Table 1. Experimental design¹

Period	Weeks of lactation	Dietary concentrate level (DM basis)		
		50%	30%	70%
Pre-experiment	1–4	All cows		
Period 1	5–10		H1 + JH1	H2 + JH2
Period 2	11–16	All cows	H2 + JH2	H1 + JH1
Nonexperimental period	16–26			
Period 3	27–32		H1 + JH1	H2 + JH2
Period 4	33–38		H2 + JH2	H1 + JH1

¹H1 and H2 = groups 1 and 2 of Holstein cows; JH1 and JH2 = groups 1 and 2 of Jersey-Holstein crossbred cows.

The efficiency with which energy is used for lactation is a key driver of production efficiency. For example, Veerkamp and Emmans (1995) found that high genetic merit Holstein dairy cows had the capacity to partition more energy into milk and less into body tissue, in comparison with medium genetic cows. Similarly, Yan et al. (2006) reported that Holstein dairy cows partitioned more energy into milk and less into body tissue than did Norwegian dairy cows during early lactation, although this difference disappeared during late lactation. In beef cattle, Frisch and Vercoe (1984) also reported that maintenance energy requirements varied according to the production potential of different beef cattle breeds. However, little information is available in the literature on the effect of crossbreeding on energy efficiencies and energy partitioning between milk and body tissue. Indeed, for Jersey crossbred cows, one of the most popular dairy cow crosses on dairy farms in many countries, virtually no information is available on the relative intake potential of Holstein and Jersey-Holstein crossbred cows within confinement systems. One exception is the study by Heins et al. (2008) in which neither food intake or feed efficiency differed between Holstein and Jersey-Holstein crossbred cows. However, within this study, feed efficiency was expressed as the ratio of fat + protein yield divided by DM intake and ECM yield divided by DM intake. No study has been identified in which nutrient digestion and detailed energy use of Holstein and Jersey-Holstein cows have been compared. Thus, the objective of the present study was to examine the efficiency of energy use of Holstein and Jersey-Holstein dairy cows offered mixed diets of grass silage with 2 levels of concentrates. The second objective was to evaluate the effects of stage of lactation on energy efficiencies within each cow genotype.

MATERIALS AND METHODS

Animal, Diet, and Experimental Design

Eight Holstein and 8 Jersey-Holstein crossbred dairy cows (all primiparous) were used in a repeated

2 (genotype) × 2 (concentrate level) factorial design study, with a total of 4 periods (each of 6-wk duration). Holstein cows were selected from a high genetic merit herd at the Agri-Food and Biosciences Institute (Hillsborough, Co. Down, UK) and their annual milk yield (305 d) obtained after the present study was, on average, 6,011 (SD 1,011.8) kg. The corresponding value for Jersey Holstein was 6,105 (SD 673.8) kg. From calving until approximately 28 d postcalving, cows were offered a standard complete diet comprising grass silage and concentrates (proportionally 0.5:0.5, DM basis). Thereafter, for the next 6 wk (period 1), one-half of the cows within each genotype (group 1) were offered a diet containing a high proportion of concentrates (proportionally 0.7 concentrates and 0.3 grass silage, on a DM basis), whereas the remaining cows (group 2) were offered a diet containing a low proportion of concentrates (proportionally 0.3 concentrates and 0.7 grass silage, on a DM basis). Cows within each genotype were allocated to either group 1 or group 2 so that groups were balanced for calving date, BW, milk yield, and BCS. During period 2, the diets offered to the group 1 and group 2 cows of each genotype were reversed. On completion of period 2, all cows were offered the standard diet (described previously) for a 10-wk nonexperimental period. From approximately wk 27 of lactation onwards, the experimental design was repeated during a third and fourth period. The experimental design is presented in Table 1.

The concentrate offered consisted of 170 g of barley/kg, 170 g of wheat/kg, 170 g of molassed sugar beet pulp/kg, 170 g of citrus pulp/kg, 230 g of soybean meal/kg, 70 g of rapeseed meal/kg, and 20 g of molasses/kg (air dry basis), and contained 880 g of DM/kg, 18.3 MJ of gross energy (GE)/kg of DM, and 57, 228, 118, and 200 g/kg of DM of ash, CP, ADF, and NDF, respectively. In addition, each cow was supplemented with 140 g/d of a mineral/vitamin premix. All rations were mixed daily using a complete diet mixer wagon. The silage offered throughout the experiment was produced from the primary growth of a perennial ryegrass-based

sward. In order to ensure that the quality of the silage offered during the final 10 d of each of the 4 experimental periods was of a consistent composition, sufficient silage for each of these periods was frozen in thin layers in polythene bags (approximately 200 kg/bag) at the beginning of the first period. This allowed silage to be thawed rapidly (within 48 h) for subsequent feeding. The silage had a pH of 3.77, an ammonia N content of 8% of total N, a DM content of 288 g/kg, a GE content of 18.1 MJ/kg of DM and an ash, CP, ADF, and NDF content of 94, 161, 276, 477 g/kg of DM, respectively.

Fresh food was offered daily at approximately 1000 h, with food offered at proportionally 1.1 of the previous day's intake. All cows were allowed free access to drinking water, and were milked twice daily commencing at approximately 0700 and 1530 h. During the first 31 d of each experimental period, cows were housed in cubicle accommodation as a single group, with access to the specified diet controlled via an electronic Calan gate feeding system. Cows were then transferred in pairs (one of each genotype) to a metabolism unit and tied individually in stalls with free access to drinking water. Each nutrient utilization trial encompassed an 8-d period (6-d feeding period commencing 2 d before the first collection of feces and urine) and a 6-d total feces and urine collection period. Feces were collected in a plastic collection tray (96 × 108 × 36 cm) placed behind each cow. Urine was collected in a 25-L plastic container via a flexible plastic tube, which was attached to a urine separation system. This was held in position over the vulva by attaching it using a "hook and loop" self-adhesive fastening tape to a patch glued on either side of the cow's tail head. Afterward, cows were placed in indirect open-circuit respiration calorimeter chambers for 3 d, with gaseous exchange measured during the final 48 h. The procedure of measurements and calibration of the chambers have been reported by Gordon et al. (1995a) and Yan et al. (2000), respectively. Heat production was calculated using the equation of Brouwer (1965). During the 8-d period in the metabolism unit and the 3-d period in the respiration chambers, diets were prepared individually in a mini mixer using the thawed silage as described previously.

Measurements

Throughout the experiment, total food intake for each individual cow was recorded daily, either electronically using a Calan gate feeding system (when in cubicle accommodation), or as the difference between food offered and the uneaten component of the diet (during the period in the metabolism unit and calorimeter chambers). Fresh silage offered was sampled daily,

with a subsample analyzed for oven DM content (85°C for 24 h), whereas a second subsample was dried at 60°C for 48 h. These latter samples were either bulked weekly during the first 4 wk of each period, or kept as individual samples during the final 11 d of each period when energy metabolism data were measured in the metabolism unit and calorimeter chambers. These bulked or individual day samples were subsequently used for determination of ADF, NDF, ash, and water-soluble carbohydrates concentrations. Twice weekly during the first 4 wk of each period and daily during the final 11 d of each period, an additional fresh silage sample was taken for determination of concentrations of GE, CP, and fermentation variables (pH, ammonia, VFA, lactic acid, and alcohol). Samples of concentrates were taken weekly during the first 4 wk of each period and daily during the final 11 d of each period; these samples were used for analysis of oven DM, GE, N, ADF, NDF, and ash concentrations.

Feces and urine outputs of cows during the final 6 d in the metabolism unit were recorded and sampled daily as a proportion (5%) of total excretion of feces (by weight) and urine (by volume). The 6-d samples of feces and urine were separately mixed and a representative sample taken for analysis as follows: feces samples were analyzed for oven DM, N, GE, ADF, NDF, and ash concentrations and urine samples were analyzed for GE and N concentrations. The methods adopted for analysis of silage, concentrate, feces, and urine samples were as described by Mayne and Gordon (1984). Crude protein concentration was determined as Kjeldahl N × 6.25.

Milk yields were recorded daily at each milking throughout the experiment. Milk composition (fat, protein, lactose, and energy) was determined on a weekly basis from one consecutive a.m. and p.m. milking during the first 4 wk of each period, and on a daily basis during the digestibility and chamber measurement period. Separate analysis was completed for a.m. and p.m. samples, and a weighted milk composition for the 24-h sampling period was calculated on the basis of recorded a.m. and p.m. milk yields. Milk composition was determined using an infrared milk analyzer. Live weight and BCS of the cattle were determined weekly. Body condition of each cow was assessed on a scale of 1 (very thin) to 5 (very fat; Mulvany, 1977).

Statistical Analyses

The effects of cow genotype and concentrate level on DM intake, live weight, BCS, milk production, energy intake and outputs, and energy efficiencies were analyzed using 2-way (cow genotype vs. concentrate level)

Table 2. Effects of cow genotype and nutritional level on animal performance

Item	30% concentrate level		70% concentrate level		SE	Significance ¹	
	Holstein	Jersey-Holstein	Holstein	Jersey-Holstein		Genotype	Concentrate level
Feed intake and live weight							
Silage DM intake (kg/d)	10.4	10.9	5.3	5.7	0.17	*	***
Concentrate DM intake (kg/d)	4.1	4.3	11.3	12.1	0.21	*	***
Total DM intake (kg/d)	14.6	15.2	16.6	17.8	0.34	**	***
Live weight (kg)	480	466	487	473	10.7	NS	NS
BCS	2.53	2.70	2.58	2.75	0.067	*	NS
Milk production							
Milk yield (kg/d)	18.2	17.9	21.7	20.2	0.71	NS	***
ECM yield (kg/d)	18.1	19.9	21.8	23.4	0.73	*	***
Milk fat (g/kg)	40.5	47.0	38.5	48.1	1.34	***	NS
Milk protein (g/kg)	33.8	37.0	35.4	39.8	0.75	***	**
Milk lactose (g/kg)	45.2	47.6	48.7	48.7	0.98	NS	*
Milk energy (MJ/kg)	3.10	3.51	3.11	3.58	0.072	***	NS

¹No significant interaction existed for any variable between cow genotype and concentrate level.

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

ANOVA with experimental period as blocking. The effects of stage of lactation within each cow genotype and interactions between stage of lactation and cow genotype were also undertaken using 2-way ANOVA with cow pair as blocking (discussed later). The linear regression technique of ME intake against milk energy output or heat production (**HP**) was used to examine effects of cow genotype on energy use efficiency. The statistical program used in the present study was Genstat 6.1 (6th edition; Lawes Agricultural Trust, Rothamsted, UK).

Energy-corrected milk yield (kg/d) was calculated as total milk energy output (MJ/d) divided by milk energy concentration of 1 kg of standard milk (3.1 MJ/kg; fat, protein, and lactose concentrations = 40, 32, and 48 g/kg, respectively).

The efficiency of ME use for lactation (k_l) was calculated as

$$k_l = \frac{E_l + aE_g}{\text{MEI} - \text{ME}_m},$$

where E_g = tissue energy balance (MJ/d); E_l = milk energy output (MJ/d); MEI = ME intake (MJ/d); ME_m = ME requirement for maintenance (MJ/d) estimated from the present study; $a = 0.84$ if $E_g < 0$, or $a = 0.95$ if $E_g > 0$ (AFRC, 1990).

RESULTS

No significant interaction existed between cow genotype and concentrate feed level for feed intake, milk production, energy intake, energy output, or energy efficiency. Thus, the main effects of cow genotype and concentrate feed levels are presented in this paper.

Feed Intake and Animal Performance

Increasing the concentrate proportion in the diet from 30 to 70% produced a significant increase in total DM intake, milk yield, ECM yield ($P < 0.001$), and protein ($P < 0.01$) and lactose ($P < 0.05$) concentration in milk (Table 2). However, dietary concentrate level had no significant effect on live weight, BCS, or the fat or energy concentration of milk. Across the 2 dietary concentrate levels, Jersey-Holstein cows had significantly higher silage, concentrate ($P < 0.05$), and total DM intakes ($P < 0.01$), and a higher BCS ($P < 0.05$), than did the Holstein cows, whereas live weight was similar between the 2 genotypes. Whereas milk yield was not affected by genotypes ($P > 0.05$), Jersey-Holstein cows had a significantly higher ECM yield ($P < 0.05$), a reflection of the higher fat and protein concentrations in the milk of the Jersey-Holstein cows ($P < 0.001$). Cow genotypes had no significant effect on milk lactose concentration.

Energy and Nutrient Digestibility

No significant effects of either cow genotype or concentrate level existed on DM, OM, energy, or nitrogen digestibility (Table 3). Although digestible OM in total DM was unaffected by cow genotype, it was higher with the diet containing the high concentrate level ($P < 0.05$).

Energy Intake and Output, and Efficiency of Energy Use

Across the 2 cow genotypes, increasing dietary concentrate level significantly increased GE intake, HP, and energy outputs in feces ($P < 0.001$), urine ($P <$

Table 3. Effects of cow genotype and nutritional level on energy and nutrient digestibility

Item	30% concentrate level		70% concentrate level		SE	Significance ¹	
	Holstein	Jersey-Holstein	Holstein	Jersey-Holstein		Genotype	Concentrate level
DM digestibility	0.797	0.798	0.793	0.792	0.0046	NS	NS
OM digestibility	0.813	0.816	0.811	0.81	0.0043	NS	NS
Digestible OM in DM	0.745	0.748	0.756	0.755	0.0039	NS	*
Energy digestibility	0.774	0.779	0.777	0.777	0.0054	NS	NS
Nitrogen digestibility	0.687	0.687	0.695	0.702	0.0105	NS	NS

¹No significant interaction existed for any variable between cow genotype and concentrate level.

* $P < 0.05$.

0.01), and milk ($P < 0.001$), but had no significant effects on methane energy output or energy balance (Table 4). Cows offered the high dietary concentrate level had a significantly higher ME/GE ($P < 0.05$) and ME/digestible energy (DE; $P < 0.001$) across the 2 genotypes. However, dietary concentrate level had no significant ($P > 0.05$) effect on energy partitioning between milk (milk energy/ME intake) and body tissue (energy balance/ME intake) or k_l . Across dietary concentrate levels, Jersey-Holstein cows had a significantly higher GE intake, urinary energy output, methane energy emission, and milk energy output ($P < 0.05$), and lower HP/ME intake ($P < 0.05$) than did Holstein cows. However, cow genotype had no significant effects on fecal energy output, HP, or energy balance. In addition, cow genotype had no significant effects on DE/GE, ME/GE, ME/DE, k_b or energy partitioning between milk (milk energy/ME intake) and body tissue (energy balance/ME intake).

Because no significant interaction was found between cow genotype and concentrate level for any variable examined, energy metabolism data from the 2 concentrate levels within each genotype were pooled and used to develop relationships between ME intake and HP and milk energy output. These relationships are presented in Table 5 and Figure 1, and were used to examine effects of cow genotype on energy efficiency. In order to examine the effect of genotype on these relationships, each pair of relationships was developed with a common coefficient and different constants. All relationships were significant ($P < 0.001$). No significant difference was found in constants in any pair of relationships between the 2 genotypes (Eq. 1a vs. 1b, 2a vs. 2b, 3a vs. 3b, and 4a vs. 4b; Table 5). The constants in each pair of relationships were similar. The ME_m calculated from equations 1a and 1b were similar between Holstein and Jersey-Holstein dairy cows (0.71 vs. 0.67 MJ/kg^{0.75}). These findings support the results

Table 4. Effects of cow genotype and nutritional level on energy intake and outputs and energy efficiencies

Item ¹	30% concentrate level		70% concentrate level		SE	Significance ²	
	Holstein	Jersey-Holstein	Holstein	Jersey-Holstein		Genotype	Concentrate level
Energy intake and output (MJ/d)							
GE intake	269.0	280.3	306.0	328.1	6.59	*	***
Fecal energy	60.7	62.1	68.1	73.5	2.16	NS	***
Urinary energy	9.8	10.5	10.7	11.7	0.39	*	**
Methane energy	18.9	19.9	18.4	19.9	0.49	*	NS
HP	116.0	118.6	134.0	133.7	2.57	NS	***
Milk energy	56.0	62.2	66.9	72.2	2.23	*	***
Energy balance	7.5	7.0	7.8	17.1	3.80	NS	NS
Energy use							
DE/GE	0.774	0.779	0.777	0.777	0.0054	NS	NS
ME/GE	0.667	0.670	0.681	0.680	0.0059	NS	*
ME/DE	0.861	0.860	0.876	0.876	0.0034	NS	***
HP/ME intake	0.650	0.637	0.647	0.602	0.0119	*	NS
Milk energy/ME intake	0.314	0.336	0.326	0.328	0.0108	NS	NS
Energy balance/ME intake	0.037	0.027	0.027	0.070	0.0191	NS	NS
k_l	0.604	0.575	0.562	0.581	0.0143	NS	NS

¹HP = heat production; DE = digestible energy; GE = gross energy; k_l = efficiency of ME use for lactation.

²No significant interaction existed for any variable between cow genotype and concentrate level.

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

Table 5. Comparison of constants between Holstein and Jersey-Holstein dairy cows in linear regression equations of ME intake against heat production (HP) and milk energy output¹

Genotype	Equation ²	r ²	Equation no.
Holstein	$E_{l(0)} = 0.581_{(0.0393)} \text{ MEI} - 0.413_{(0.0753)}$	0.81	1a
Jersey-Holstein	$E_{l(0)} = 0.581_{(0.0393)} \text{ MEI} - 0.386_{(0.0815)}$		1b
Holstein	$\text{HP} = 0.416_{(0.0417)} \text{ MEI} + 0.433_{(0.0799)}$	0.63	2a
Jersey-Holstein	$\text{HP} = 0.416_{(0.0417)} \text{ MEI} + 0.409_{(0.0865)}$		2b
Holstein	$\text{HP/MEI} = -0.114_{(0.0216)} \text{ MEI} + 0.864_{(0.0414)}$	0.37	3a
Jersey-Holstein	$\text{HP/MEI} = -0.114_{(0.0216)} \text{ MEI} + 0.854_{(0.0448)}$		3b
Holstein	$(\text{HP} - \text{ME}_m) = 0.416_{(0.0417)} \text{ MEI} - 0.278_{(0.0799)}$	0.66	4a
Jersey-Holstein	$(\text{HP} - \text{ME}_m) = 0.416_{(0.0417)} \text{ MEI} - 0.255_{(0.0865)}$		4b

¹No significant difference existed for constants in any pair of the relationships; values in subscript parentheses are SE data.

²The unit for all variables of energy intake and output = MJ/kg^{0.75}; $E_{l(0)}$ = milk energy output adjusted to zero energy balance; HP = heat production; MEI = ME intake; ME_m = ME requirement for maintenance (MJ/d), estimated respectively from the present Eq. 1a and 1b for Holstein and Jersey-Holstein cows.

presented in Table 4 that the efficiency of ME use was not affected by genotype.

DISCUSSION

Ample evidence exists in the literature indicating that within a breed of dairy cow, ME intake, milk production, and energy digestibility and metabolizability increase with increasing dietary concentrate proportions. Consequently, the present discussion will focus on the effects of cow genotype and stage of lactation on milk production efficiency and energy use.

Effects of Cow Genotype on Energy Use Efficiency

Food intake is positively related to levels of milk production in dairy cows. However, few studies have compared the food intake of Holstein and Jersey-Holstein dairy cows within a confinement situation. One exception is the study by Heins et al. (2008), which also involved primiparous cows, and in which genotype had no effect on food intake or fat and protein yield. Whereas the higher intake of the Jersey-Holstein cows in the present study is perhaps unexpected, the crossbred cows were similar in live weight to the Holstein cows, in contrast to the study by Heins et al. (2008) in which the crossbred cows were approximately 30 kg lighter. Although milk yield was unaffected by genotype in the current study, the Jersey-Holstein cows produced milk with a higher concentration of fat and protein and as such they had a higher ECM yield than did the Holstein cows. A similar result was also reported by Prendiville et al. (2009), who found that Jersey-Holstein cows produced a marginally higher fat and protein yield than did pure Holstein cows during a whole lactation period. Nevertheless, in the present study, the gross efficiency of ME use, when expressed as milk energy output as a proportion of ME intake, did not differ significantly

between the 2 cow genotypes. Heins et al. (2008) also reported that the feed efficiency for d 4 to 150 of lactation was similar for Jersey-Holstein and pure Holstein cows. In a modeling analysis, Schwager-Suter et al. (2001) observed greater production efficiency for Jersey-Holstein than for Holstein cows. However, previous studies have shown that breeding programs that have focused on milk yield have resulted in increased energy use efficiencies, especially during early lactation (van Arendonk et al., 1991; Veerkamp et al., 1994). Therefore, the results obtained in the present study indicated that crossbreeding of Holstein cows with Jersey sires had no negative effects on production efficiency.

The above results are supported by the evidence obtained in the present study that crossbreeding of Holstein cows with Jersey sires had no effects on energy efficiencies, in terms of energy digestibility and metabolizability. These values were almost identical between Holstein and Jersey-Holstein cows. Differences in energy efficiency between the 2 genotypes were also examined by development of a range of linear relationships using ME intake against HP or milk energy output, with energy metabolism data for each genotype derived from both high- and low-concentrate diets. With a common coefficient, no significant difference existed in the constants in any pair of the relationships between the 2 genotypes, indicating that cow genotype had little effect on the efficiency of ME use for production of milk and body tissue or the ratio of energy expenditure as a proportion of ME intake. The effects of cow genotype on energy efficiency were further evaluated in the present study by relating ME intake to the inefficiency of ME use for production of milk and body tissue, assuming no energy requirement for pregnancy and other functions (e.g., hair growth). With a common coefficient, the constant from Holstein cow data was not significantly different from that from Jersey-Holstein cow data. When the constant was forced to zero, the

Figure 1. Relationships between ME intake and heat production (A), milk energy output adjusted to zero energy balance (B), and heat production as a proportion of ME intake (C) for Holstein and Jersey-Holstein crossbred cows.

difference between HP and ME_m was 0.30 of ME intake for both genotypes. Furthermore, the ME_m values for Holstein and Jersey-Holstein cows are similar (0.71 vs. 0.67 MJ/kg^{0.75}). These 2 ME_m values are marginally higher than those published recently (Agnew and Yan, 2000; Kebreab et al., 2003), but are within the range of 0.61 to 0.75 (average 0.67) reported by Yan et al. (1997) using a range of linear and multiple regression techniques. The high ME_m values from both genotypes in the present study may be attributed to the fact that cows used in the present study were in the first lactation, which may have a higher metabolic rate than do older cows (Agnew and Yan, 2000).

When calculated from individual animal data from periods 1 to 4 (early to late lactation), no significant differences existed in the k_l between Holstein and Jersey-Holstein cows. The mean k_l value in the present study (0.581) was at the upper range (0.50 to 0.58) reported by Kebreab et al. (2003), but similar to values reported by Gordon et al. (1995b) and Kirkland and Gordon (1999; 0.58 and 0.59, respectively). Several previous studies have also found that k_l was unaffected by cow genetic merit. Nayak and Maitra (1983) found that energy use efficiencies for milk production did not differ among 4 breeds of cows (Jersey, Holstein-Friesian, and Brown Swiss half-breeds with Haryana). Gordon et al. (1995b) and Ferris et al. (1999) reported that no difference existed in k_l between high and medium merit Holstein cows. Yan et al. (2006) compared the energy efficiencies between Holstein and Norwegian cows during lactation wk 1 to 42 and found that cow genotype had no significant effect on k_l value. Agnew and Yan (2000), in a review of calorimetric data of lactating dairy cows published by 2000, reported that dietary and animal factors had little effect on k_l values. Therefore, the results from the present study support the view that cow genotype has little effect on k_l values of dairy cows. The crossbreeding of Holstein cows with Jersey sires does not alter the metabolic rate or the efficiency of ME use for milk production of Holstein cows.

Ample evidence indicates that within the same breed, high genetic merit cows have the ability to partition more energy into milk and less into body tissue than do low genetic merit cows (Veerkamp and Emmans, 1995; Agnew and Yan, 2000). Similar effects were reported by Tyrrell et al. (1990) and Yan et al. (2006) when comparisons were made between Holstein and Jersey, and Holstein and Norwegian dairy cows, respectively. Veerkamp et al. (1994) reported that, within the Holstein breed, high genetic cows had considerably higher milk energy output as a proportion of ME intake than did low genetic animals during the first 26 wk of lactation. Yan et al. (2006) found that Holstein cows partitioned more energy into milk than did Norwegian

cows during early to mid lactation, but the difference disappeared during late lactation. Bryant et al. (2003) reported that high genetic merit Jersey cows partitioned a significantly higher proportion of ME intake into milk than did low genetic merit Jersey cows in any stage of lactation. However, in the present study, no significant difference was found in milk energy output as a proportion of ME intake between Holstein and Jersey-Holstein cows, and cow genotypes also had no significant effects on energy partitioning into body tissue (energy balance/ME intake). Pryce et al. (1998) reported that high genetic merit cows with high milk production were associated with a high level of tissue energy loss. High genetic merit cows used more body reserves for milk production during early lactation (Bryant et al., 2003; Yan et al., 2006). However, the results obtained in the present study did not show any significant difference in energy retention between Jersey-Holstein cows and Holstein cows. The proportion of consumed ME used for tissue energy gain (energy retention/ME intake) was similar between Jersey-Holstein and Holstein cows. The results obtained in the present study indicated that crossbreeding of Holstein cows with Jersey sires did not alter energy partitioning between milk and body tissue.

Effects of Stage of Lactation on Energy Use Efficiency

The present study was also designed to examine the effects of stage of lactation on energy efficiencies within each cow genotype. To achieve this objective, silage was frozen during the early part of period 1 and the frozen silage offered during the energy metabolism measurements undertaken during each of periods 1 to 4. This approach was adopted to overcome the potential effects on energy metabolism of offering silages of different qualities in early and late lactation. In order to minimize potential interactions between concentrate level and stage of lactation, the statistical comparison was undertaken using the pooled data for only 2 stages of lactation (i.e., early vs. late). The early lactation data set contained data obtained in the first 2 periods and the late lactation data set contained data for the second 2 periods. Thus, each data set contained data derived from both low and high concentrate levels for each cow. Energy metabolism data used in the present study were measured around wk 10, 16, 32, and 38 of lactation for periods 1, 2, 3, and 4, respectively. The effects of stage of lactation on energy efficiencies are presented in Table 6. No significant effects of stage of lactation were found on energy digestibility and metabolizability or on dietary ME concentrations (ranging from 12.4 to 12.6 MJ/kg of DM) within each genotype. Whereas

Table 6. Effects of stage of lactation on energy intake and outputs and energy efficiency for Holstein and Jersey-Holstein dairy cows¹

Item ²	Holstein		Jersey-Holstein		SE	Significance ³	
	Period 1–2	Period 3–4	Period 1–2	Period 3–4		Genotype	Period
ME intake (MJ/d)	182.4	205.9	193.3	217.6	5.57	*	***
Milk energy (MJ/d)	61.0	62.0	68.6	65.8	2.38	*	NS
Energy balance (MJ/d)	0.2	15.1	3.9	20.3	4.44	NS	***
ME concentration (MJ/kg of DM)	12.4	12.5	12.6	12.4	0.14	NS	NS
DE/GE	0.773	0.778	0.783	0.772	0.0052	NS	NS
ME/GE	0.671	0.677	0.681	0.669	0.0057	NS	NS
HP/ME intake	0.665	0.631	0.630	0.610	0.0124	*	*
Milk energy/ME intake	0.337	0.303	0.360	0.304	0.0138	NS	**
Energy balance/ME intake	−0.003	0.066	0.011	0.086	0.0226	NS	**
k_l	0.559	0.608	0.564	0.592	0.0145	NS	**

¹Dietary concentrate level was used as block in the ANOVA for analysis of all variables.

²DE = digestible energy; GE = gross energy; HP = heat production; k_l = efficiency of ME use for lactation.

³No significant interaction existed for any variable between genotype and experimental period.

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

ME intake was significantly higher during late than during early stages of lactation within each genotype, the extra ME consumed was not used for milk production, but directed toward body tissue reserves. Moving from early to late lactation, the proportion of ME partitioned into milk (milk energy output/ME intake) decreased, whereas that partitioned into body tissue (energy balance/ME intake) increased ($P < 0.01$). A similar result was also reported by Yan et al. (2006) in a whole lactation study involving Holstein and Norwegian dairy cows. Veerkamp et al. (1994) and Veerkamp and Emmans (1995) reported that Holstein heifers were in positive energy balance after wk 8 (on average) of a 26-wk study. In the present study, k_l values significantly increased from early to late lactation ($P < 0.01$), and this was mainly due to a significantly higher HP as a proportion of ME intake in early lactation for both genotypes ($P < 0.05$). This result disagrees with that reported by Yan et al. (2006) who found that k_l values remained similar from early to late lactation with both Holstein and Norwegian dairy cows.

CONCLUSIONS

Crossbreeding Holstein dairy cows with Jersey sires had no significant effect on the efficiency of ME use for lactation, irrespective of nutritional plane. The capacity of energy partitioning between milk and body tissue was also similar between Holstein and Jersey-Holstein dairy cows. These results indicate that the high milk production potential of Holstein cows can be maintained with crossbreeding programs using Jersey Sires, which have been widely adopted to improve the health and fertility of Holstein dairy cows.

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