A comparison between Holstein-Friesian and Jersey dairy cows and their F₁ hybrid on milk fatty acid composition under grazing conditions

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ABSTRACT

The objective of this study was to investigate the effect of 2 breeds, Holstein and Jersey, and their F₁ hybrid (Jersey × Holstein) on milk fatty acid (FA) concentrations under grazing conditions, especially conjugated linoleic acid (CLA) and n-3 polyunsaturated fatty acids because of their importance to human health. Eighty-one cows (27 per breed grouping) were allocated a predominantly perennial ryegrass pasture. Samples were collected over 2 periods (June and July). Breed affected dry matter intake and milk production and composition. Holstein cows had the highest dry matter intake (18.4 ± 0.40 kg of DM/d) and milk production (21.1 ± 0.53 kg of DM/d). Holstein and Jersey × Holstein cows had similar 4% fat corrected milk, fat yield, and protein yield; with the exception of fat yield, these were all higher than for Jersey cows. Milk fat concentration was highest for Jersey cows and lowest for Holstein cows, with the hybrid cows intermediate. Total FA and linolenic acid intake (1.09 ± 0.023 and 0.58 ± 0.012 kg/d, respectively) were highest for Holstein cows. In terms of milk FA, Holstein cows had higher contents of C14:1, *cis*-9 C18:1 and linoleic acid. In turn, Jersey and Jersey × Holstein cows had higher content of C16:0. Milk concentrations of neither the *cis*-9, *trans*-11 isomer of CLA nor its precursor, vaccenic acid, were affected by breed. Nevertheless, large variation between individual animals within breed grouping was observed for CLA and estimated Δ^9 -desaturase activity. There was some evidence for a negative heterotic effect on milk concentration of CLA, with the F₁ hybrid cows having lower concentrations compared with the mid parent average. Plasma FA profile did not accurately reflect differences in milk FA composition. In conclusion, there was little evidence for either breed or beneficial heterotic effects on milk FA content with human health-promoting potential, though significant within-breed, interanimal variation was observed.

Key words: conjugated linoleic acid, Holstein, Jersey, crossbred

INTRODUCTION

Consumption of n-3 polyunsaturated fatty acids (PUFA) and conjugated linoleic acid (CLA; especially the *cis*-9, *trans*-11 isomer) have been associated with putative positive effects on human health. The n-3 PUFA are widely recommended for preventing heart disease (Hamazaki et al., 2003), whereas CLA has beneficial effects on human health as a result of its anticarcinogenic, antiatherogenic, antidiabetic, and antiadipogenic properties (Parodi, 1999; Khanal and Olson, 2004; Lock and Bauman, 2004).

Several factors can affect the PUFA content of milk. Diet-related factors are likely to be most important in terms of influencing milk PUFA concentration (Khanal and Olson, 2004), with concentrations typically being higher for animals offered high forage diets (Dewhurst et al., 2006; Elgersma et al., 2006). However, there is also evidence for significant variation between individual animals on the same diet and also between cow breeds (White et al., 2001; Kelsey et al., 2003). Most breed comparison studies have been carried out under TMR systems or with grazing animals receiving supplements. Additionally, there is little, if any, published work examining the effect of heterosis on milk fatty acid (FA) concentration. Work to date has shown Holstein cows to have higher milk content of CLA compared with Jersey cows under both TMR- and pasture-supplemented systems (White et al., 2001), but overall concentrations of PUFA were low compared with previous reports with exclusively pasture diets (Kelly et al., 1998; Elgersma et al., 2004).

Because the major source of CLA in milk is the de novo conversion of vaccenic acid (VA; *trans*-11 C18:1) to CLA via Δ^9 -desaturase (up to 93% of total CLA; Piperova et al., 2002; Lock and Garnsworthy, 2003), the activity of this enzyme could be important in the explanation of differences in milk CLA between breeds and individual animals (Khanal and Olson, 2004). However, it is important to note that higher interani-

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mal variation in estimated Δ^9 -desaturase activity was found under grazing conditions compared with TMR systems (Kelly et al., 1998). This grazing effect on the activity of this enzyme could potentially mask differences between breeds when comparisons are carried out on grazing systems.

The objective of this experiment was to study the milk FA concentration of Holstein-Friesian, Jersey, and Holstein-Friesian $\times$ Jersey (F_1) cows managed under a pasture-based system.

MATERIALS AND METHODS

The experiment took place at the Ballydague Dairy Research Farm at Moorepark Dairy Research Centre, Co. Cork, Ireland (50°07' N, 8°16' W). The soil type on the farm is a free-draining acid brown earth of sandy loam to loam texture. A predominantly perennial ryegrass (*Lolium perenne* L.) pasture was used during the experimental period.

Animal and Experimental Design

Eighty-one spring-calving dairy cows (27 Holstein-Friesian, 27 Jersey, and 27 F_1 ; mean calving date: February 12 $\pm$ 16.4 d; lactation number: 1.7 $\pm$ 0.45) were used. A total of 12, 11, and 6 sires were represented in the Holstein-Friesian, Jersey, and F_1 animals, respectively. All F_1 animals were sired by Jersey bulls and out of Holstein-Friesian cows. The Holstein-Friesian sires were of North American Holstein Friesian (84%) and New Zealand (16%) origin. The mean ($\pm$ standard deviation) PTA for the Holstein-Friesian sires used were +186 $\pm$ 112.6 kg, +11 $\pm$ 4.7 kg, +9 $\pm$ 3.1 kg, +0.06 $\pm$ 0.11%, and +0.06 $\pm$ 0.06% for milk yield, fat yield, protein yield, fat, and protein concentration, respectively (www.icbf.com; accessed April 2009). The mean ($\pm$ standard deviation) PTA for the Jersey sires used were -357 $\pm$ 180.7 kg, +14 $\pm$ 8.8 kg, +2 $\pm$ 6.9 kg, +0.62 $\pm$ 0.24%, and +0.27 $\pm$ 0.09%, respectively. The Jersey sires were of New Zealand (69%) and Danish (31%) origin. Of the 11 Jersey sires, 3 were represented in both the Jersey and F_1 cow groups. These 3 sires accounted for 20 and 23 of the Jersey and F_1 cows, respectively. All sires were representative of the sires commonly used in Ireland. Two experimental periods (June and July 2007) were evaluated. Fresh herbage was allocated to the herd (all cows grazed in a single herd) on a daily basis after the morning milking (a new paddock per day). Pregrazing herbage yield was maintained between 1,400 and 1,600 kg of DM/ha for the experimental period. A token quantity of concentrate (0.4 kg/cow per day) was offered in the milking parlor in 2 equal feeds at both the morning and evening milk-

Table 1. Herbage mass and chemical composition (mean $\pm$ SD) of selected herbage samples and concentrate offered

Item, g/kg of DM	Grass ¹		Concentrate
	Period 1	Period 2	
OM digestibility	865.0 $\pm$ 3.18	864.8 $\pm$ 3.82	—
CP	230.7 $\pm$ 9.09	234.0 $\pm$ 14.73	168.8 $\pm$ 6.74
NDF	359.8 $\pm$ 17.57	344.9 $\pm$ 25.74	213.2 $\pm$ 10.40
ADF	198.6 $\pm$ 7.36	228.1 $\pm$ 27.61	—
Ash	78.4 $\pm$ 0.59	81.0 $\pm$ 0.42	91.1 $\pm$ 0.88

¹Period 1: June 2007; period 2: July 2007.

ing (concentrate composition on a fresh weight basis was ground citrus pulp, 30.5%; barley, 23.7%; maize gluten, 24.9%; soybean meal, 14.0%; vitamins-mineral, 4.3%; and fat, 2.6%. Chemical analyses are shown in Table 1).

Sampling, Measurements, and Analyses

Milk Production and Composition. Milking took place at 0700 and 1600 h daily. Individual milk yields (kg) were recorded at each milking (Dairymaster, Causeway, Co. Kerry, Ireland). Milk fat, protein, and lactose concentrations were evaluated on 1 consecutive evening-morning milking weekly for each animal using a MilkoScan 203 (DK-3400, Foss Electric, Hillrød, Denmark).

Measurement of DMI and Sample Analysis. Dry matter intake was estimated using the n-alkane technique (Mayes et al., 1986) as modified by Dillon and Stakelum (1989). Cows were dosed twice daily for 12 d before both the morning and evening milkings with a paper pellet (Carl Roth, GmbH, Karlsruhe, Germany) containing 500 mg of dotriacontane (C_{32} -alkane). For each period, fecal grab samples were collected twice daily, from d 7 to 12, before both the morning and evening milkings, with 12 subsamples taken in total per cow. During the same period, herbage samples were manually collected with Gardena hand shears (Acu 60, Gardena International GmbH, Ulm, Germany) at a similar height to which cows grazed after each morning and evening milking in order to obtain a representative sample of the herbage actually grazed. A concentrate sample was collected daily and both the herbage and concentrate samples were frozen at -20°C after collection. Fecal grab samples were thawed and bulked (10 g of each individual subsample) by cow. Fecal samples were dried at 40°C for 48 h and milled through a 1-mm screen. The n-alkane concentrations of the dosed pellets, feces, herbage, and concentrate were determined as described by Dillon (1993).

Chemical Analysis. A daily herbage sample (approx. 0.15 kg) was collected from each paddock from d

Table 2. Fatty acid composition (mean $\pm$ SD) of selected herbage samples and concentrate offered

Fatty acid, g/kg of DM	Grass ¹		Concentrate
	Period 1	Period 2	
C14	1.2 $\pm$ 0.16	1.5 $\pm$ 0.18	1.2 $\pm$ 1.07
C16	14.6 $\pm$ 0.59	16.0 $\pm$ 1.24	23.6 $\pm$ 2.86
C16:1	2.5 $\pm$ 0.68	2.1 $\pm$ 0.03	0.8 $\pm$ 0.31
C18	1.0 $\pm$ 0.31	0.7 $\pm$ 0.02	1.2 $\pm$ 0.09
C18:1	1.0 $\pm$ 0.09	0.8 $\pm$ 0.11	13.2 $\pm$ 1.39
C18:2	6.7 $\pm$ 0.27	7.4 $\pm$ 0.15	18.5 $\pm$ 1.33
C18:3	30.0 $\pm$ 0.86	34.0 $\pm$ 0.86	1.7 $\pm$ 0.51
Total	56.9 $\pm$ 2.16	62.5 $\pm$ 2.23	60.2 $\pm$ 6.55

¹Period 1: June 2007; period 2: July 2007.

7 to 12 during both periods and stored at -20°C before being freeze-dried and milled through a 1-mm sieve before chemical analysis. The herbage samples and the concentrate were analyzed for DM content, ADF, NDF (Van Soest, 1963), ash, CP (Leco FP-428, Leco Australia Pty Ltd., Baulkham Hills, New South Wales, Australia), FA, and OM digestibility (Morgan et al., 1989). The chemical analyses are shown in Table 1.

Fatty Acid Analysis. The FA composition of the herbage and concentrate samples was analyzed by gas chromatography using a 1-step methylation procedure (Sukhija and Palmquist, 1988). Samples were injected by auto-sampler on a Varian GC 3800 (Varian Inc., Palo Alto, CA) equipped with a flame ionization detector. Fatty acid methyl esters (injected using a 10:1 split ratio) were separated on a fused silica capillary column (100 m $\times$ 0.25 mm i.d $\times$ 0.39 μm film thickness; Varian Fame Select CP 7420, Varian Inc.). The injector temperature was held at 250°C , and the detector temperature at 300°C . The initial oven temperature was 140°C (held for 10 min), which was then increased to 240°C at a rate of $4^{\circ}\text{C}/\text{min}$ (held for 17 min). Nitrogen (N_2) was used as a carrier gas and column flow was held at 2 mL/min. Results are shown in Table 2.

Blood was sampled once per period on the evening of milk sampling and was collected into tubes containing lithium heparin as an anticoagulant, placed on ice, centrifuged at $2,000 \times g$ for 10 min, and plasma stored at -20°C before analysis. Plasma lipids (1 mL) were extracted according to Folch et al. (1957), recovered in 1 mL of hexane, and methylated as described previously by Doreau et al. (2007). The extracted FA were methylated by adding 2 mL of 0.5 *N* NaOCH_3 in methanol at 50°C for 45 min followed by 2 mL of 5% HCl in methanol at 50°C for 45 min. The hexanoic phase was recovered after neutralization with 6% K_2CO_3 and centrifugation (5 min at $352 \times g$).

To determine milk FA composition, samples were taken, concurrently with blood samples, once per period

at a p.m. milking and centrifuged at 4°C ($978 \times g$) for 20 min. The cream was then harvested, flushed with N_2 for 10 to 15 s (to avoid oxidation), and stored at -20°C overnight. The following morning, cream samples were heated to 40°C and centrifuged at 30°C ($978 \times g$) for 10 min. The extracted milk fat (upper layer) was stored at -20°C until FA analysis. The FA composition of the milk fat was analyzed by gas chromatography using an adaptation of the method of Christie (1982). Approximately 1 mg of milk fat was dissolved in dried n-hexane. Methyl acetate (20 μL) and 1*M* sodium methoxide in anhydrous methanol (20 μL) were added following neutralization with a saturated solution of oxalic acid in methanol (30 μL). After centrifugation, an aliquot of the upper layer was taken for gas chromatography.

Milk and plasma FA samples were injected by auto-sampler on a Varian GC 3800 (Varian Inc.) equipped with a flame ionization detector. Fatty acid methyl esters (injected using a 10:1 split ratio) were separated on a fused silica capillary column (100 m $\times$ 0.25 mm i.d $\times$ 0.39 μm film thickness; Varian Fame Select CP 7420, Varian Inc.). The injector temperature was held at 250°C , and the detector temperature at 260°C . The initial oven temperature was 140°C (held for 5 min); it was then increased to 180°C at a rate of $4^{\circ}\text{C}/\text{min}$ (held for 5 min) and then increased to 220°C at a rate of 4°C (held for 20 min). Nitrogen (N_2) was used as carrier gas. Pressure column was held at 275 kPa.

Statistical Analysis

Statistical analyses were carried out using SAS software (SAS Institute, 2002). Data were analyzed using the MIXED procedure and significant differences were tested using the PDIF command adjusted by the Tukey test. For all the variables, cow was included as a random effect and the model used was as follows:

$$Y_{ijk} = \mu + B_i + P_j + C_k + b_1X_{ijk} + b_2X_{ijk} + B_i \times P_j + e_{ijk},$$

where Y_{ijk} represents the response (DMI, milk production and composition, FA intake, milk FA, plasma FA); μ is the mean; B_i is the breed ($i = 1$ to 3); P_j is the period ($j = 1$ to 2); C_k is the random effect of the cow; b_1X_{ijk} and b_2X_{ijk} are the covariables DIM and parity, respectively (primiparous and multiparous); and e_{ijk} is the residual error term. Significant differences were declared at $P < 0.05$ and trends toward statistical significance were declared at $P < 0.10$. Interaction terms were removed where not statistically significant. Regression and correlations analyses were performed using the REG and CORR procedures of SAS (SAS Institute, 2002). To re-

Table 3. Effect of breed on animal performance

Item	Breed			SED ¹	Significance ²		
	Holstein-Friesian	Jersey × Holstein	Jersey		Breed	Period	Breed × period
DMI, kg/d	18.4 ^a	17.3 ^b	15.3 ^c	0.40	**	**	NS
Milk production, kg/d	21.1 ^a	18.4 ^b	14.5 ^c	0.53	**	**	*
Milk fat, %	3.79 ^c	4.45 ^b	5.09 ^a	0.130	**	NS	NS
Fat yield, kg/d	0.80 ^{ab}	0.81 ^a	0.75 ^b	0.026	*	**	NS
Milk protein, %	3.43 ^c	3.76 ^b	4.01 ^a	0.054	**	*	NS
Protein yield, kg/d	0.72 ^a	0.69 ^a	0.58 ^b	0.019	**	**	NS
4% FCM, kg/d	20.4 ^a	19.5 ^a	17.0 ^b	0.52	**	**	NS

^{a-c}Means within a row with different superscripts differ ($P < 0.05$).

¹Standard error of the difference.

²* $P < 0.05$; ** $P < 0.01$.

late intake of precursors to milk FA content, regression analyses and correlations were performed between VA, CLA, and linolenic acid (**LNA**; C18:3 n-3) content in milk and FA intake (total FA and LNA intake). Regression analysis was performed to assess the usefulness of plasma VA as a predictor of milk VA and CLA content. Additionally, milk VA concentrations were regressed on concentrations of CLA in milk.

RESULTS

DMI and Animal Performance

The effect of breed and period are shown in Table 3. There was a breed × period interaction for milk production ($P < 0.05$), manifested by the F₁ cows at first period and Holstein cows at second period having similar milk production. Overall, all milk production-related variables measured were affected by period, decreasing from period 1 to period 2 (data not shown) as lactation progressed.

As expected, breed affected DMI and milk production and composition (Table 3). Holstein cows had the highest DMI and milk production ($P < 0.01$) and Jersey cows the lowest, with F₁ cows intermediate. Although milk fat concentration was highest for Jerseys and lowest for Holsteins, with F₁ cows intermediate ($P < 0.01$),

daily milk fat yield was similar for Holstein and F₁ cows but lower for Jersey cows compared with the F₁ cows ($P < 0.05$). Overall, 4% FCM was higher for both the Holstein and F₁ animals than for the Jersey animals ($P < 0.05$). Milk concentration of protein was highest for Jersey cows and lowest for Holstein cows, with intermediate values for F₁ cows. However, daily yield of milk protein was higher for both the Holstein and F₁ animals compared with the Jersey animals.

Fatty Acid Intake

Intake of LNA and total FA were higher for Holstein cows, consistent with patterns in DMI (Table 4). Linoleic acid (**LA**; *cis*-9,*cis*-12 C18:2 n-6) intake was lower for Jersey cows and similar between Holstein and F₁ cows ($P < 0.01$). Period of sampling affected only the total FA intake, being higher in the first period (1.04 kg/d for period 1 vs. 0.98 kg/d for period 2; $P < 0.05$).

Milk Fatty Acid Composition

Many of the saturated FA in milk were decreased in the second period (C8:0 to C15:0), and this effect was also noted in a lower content of saturated FA and medium-chain FA (most of the medium-chain FA were

Table 4. Effect of breed on fatty acid intake and transference to milk

Item	Breed			SED ¹	Significance ²		
	Holstein-Friesian	Jersey × Holstein	Jersey		Breed	Period	Breed × period
Total fatty acids intake, kg/d	1.09 ^a	1.03 ^b	0.91 ^c	0.023	**	*	NS
Linolenic acid intake, kg/d	0.58 ^a	0.54 ^b	0.48 ^c	0.012	**	NS	NS
Linoleic acid intake, kg/d	0.13 ^a	0.13 ^a	0.11 ^b	0.003	**	†	NS
Linolenic acid transferred to milk, ³ %	0.84	0.91	0.85	0.053	NS	NS	NS

^{a-c}Means within a row with different superscripts differ ($P < 0.05$).

¹Standard error of the difference.

²† $P < 0.10$; * $P < 0.05$; ** $P < 0.01$.

³Total amount of linolenic acid in milk/linolenic acid intake.

Table 5. Effect of breed on milk fatty acid composition

Fatty acid, g/kg of total fatty acids	Breed			SED ¹	Significance ²		
	Holstein-Friesian	Jersey × Holstein	Jersey		Breed	Period	Breed × period
C4:0	64.5	60.4	61.7	4.22	NS	NS	NS
C6:0	38.8	36.9	39.2	2.43	NS	NS	NS
C8:0	22.0	20.7	22.1	1.25	NS	**	NS
C10:0	42.0	41.7	44.6	2.48	NS	**	NS
C12:0	42.9	43.1	44.4	1.99	NS	**	NS
C14:0	116.7	120.1	116.3	2.93	NS	**	NS
C14:1	11.8 ^a	10.7 ^{ab}	9.7 ^b	0.63	**	**	NS
C15:0	12.7 ^a	12.7 ^a	11.7 ^b	0.37	*	**	†
C16:0	237.5 ^b	256.1 ^a	255.3 ^a	6.36	**	NS	NS
C16:1	13.8	13.8	13.4	0.57	NS	†	†
C17:0	4.5	4.5	4.2	0.20	NS	NS	NS
C18:0	79.7	81.6	83	3.60	NS	†	NS
<i>cis</i> -9 C18:1	158.1 ^a	153.5 ^{ab}	139.3 ^b	6.84	*	NS	NS
<i>trans</i> -11 C18:1 (vaccenic acid)	43.4	39.7	45	3.56	NS	NS	NS
<i>cis</i> -9, <i>cis</i> -12 C18:2 n-6 (linoleic acid)	5.9 ^a	4.6 ^b	4.7 ^b	0.38	**	**	NS
<i>cis</i> -9, <i>trans</i> -11 C18:2 (conjugated linoleic acid)	17.2	15.0	15.6	1.28	NS	NS	NS
C18:3 n-3 (linolenic acid)	6.6	6.5	6	0.35	NS	NS	NS
SFA ³	658.8 ^b	679.1 ^{ab}	689 ^a	11.92	*	*	NS
UFA ⁴	273.6 ^a	255.6 ^{ab}	246.0 ^b	10.88	*	**	NS
UFA:SFA	0.45 ^a	0.40 ^{ab}	0.36 ^b	0.026	**	NS	NS
n-6 ⁵	9.4 ^a	8.0 ^{ab}	7.0 ^b	0.62	**	**	NS
n-3 ⁶	6.9	6.7	6.3	0.37	NS	NS	NS
n-3:n6	0.77 ^b	1.01 ^a	0.99 ^{ab}	0.100	*	NS	NS
SCFA ⁷	124.6	117.6	124.1	7.96	NS	NS	NS
MCFA ⁸	485.6 ^b	505.8 ^a	504.3 ^{ab}	8.52	*	**	NS
LCFA ⁹	321.8	311.2	307.1	12.59	NS	**	NS
Δ ⁹ -desaturase index ¹⁰	0.09 ^a	0.08 ^b	0.08 ^b	0.004	*	†	NS

^{a,b}Means within a row with different superscripts differ ($P < 0.05$).

¹Standard error of the difference.

²† $P < 0.10$; * $P < 0.05$; ** $P < 0.01$.

³Saturated fatty acids; sum of C10:1, C14:1, C16:1, C17:1, C18:1, vaccenic acid, linoleic acid, conjugated linoleic acid, and linolenic acid.

⁴Unsaturated fatty acids; sum of C4:0, C6:0, C8:0, C10:0, C11:0, C12:0, C13:0, C14:0, C15:0, C16:0, C18:0, C20:0, C21:0, C22:0, and C24:0.

⁵Sum of linoleic acid, *trans*-9,*trans*-12 C18:2 n-6, γ -C18:3 n-6, C20:3 n-6, and C20:4 n-6.

⁶Sum of linolenic acid, C20:5 n-3, and C22:6 n-3.

⁷Short-chain fatty acids; sum from C4:0 to C8:0.

⁸Medium-chain fatty acids; sum from C10:0 to C16:1.

⁹Long-chain fatty acids; sum from C17:0 to C22:6.

¹⁰C14:1/(C14:0 + C14:1).

saturated FA) in the second period (data not shown). In contrast, n-6 FA, LA, unsaturated FA, and long-chain FA were higher in the second period (data not shown). Additionally, C18:0 and CLA tended to be higher in the second period. The effect of cow breed on milk FA composition is shown in Table 5. Holstein animals had higher milk content of C14:1, *cis*-9 C18:1, and LA. In turn, Jersey and F₁ animals had higher content of C16:0 ($P < 0.01$). No statistically significant differences were found for CLA across breeds, even though Holsteins had a numerically higher content (Table 5). Additionally, VA was not different across breeds ($P > 0.10$). A strong relationship was found between milk concentrations of VA and CLA [CLA = 1.93 (SD 0.637) + 0.38 (SD 0.013) × VA; $R^2 = 0.79$; $P < 0.01$].

Saturated FA were higher for Jersey cows, intermediate for F₁ cows, and lower for Holstein cows (P

< 0.05). The opposite pattern was evident for PUFA content, being highest for Holsteins and lowest for Jerseys (Table 5). This result was manifested in a higher unsaturated FA:saturated FA ratio for Holsteins (0.45; $P < 0.01$). The n-6 PUFA were higher in Holsteins because of the higher content of LA (Table 5); in consequence, because no differences were found for LNA and n-3 FA among breeds, Holstein animals had the lowest n-3:n-6 ratio and F₁ animals had the highest ($P < 0.05$). Medium-chain FA were higher for Jersey and F₁ animals ($P < 0.05$), consequently with the higher content of C16:0.

Plasma Fatty Acid Composition

Plasma concentration of C18:0 was higher in the first period, whereas LA and LNA were higher in the sec-

ond period (data not shown). Additionally, *cis*-9 C18:1 tended to be higher in the first period.

Differences only in minor FA (*iso*-C15:0, C15:0) were found between breeds (Table 6). No difference was found for VA or LNA ($P > 0.10$). It is important to note that CLA was not detected in most of the plasma samples and, for this reason, results are not shown.

Relationships Between FA in Milk, FA in Plasma, and FA Intake

No significant relationships were found between FA in milk (LNA, CLA, VA) and FA intake (total and LNA intake; $P > 0.05$). There was a relationship between VA in plasma and VA in milk [milk VA = $25.9 + (8.0 \times \text{plasma VA})$; $R^2 = 0.20$; $P < 0.01$] and also between VA in plasma and CLA in milk [milk CLA = $10.5 + (2.5 \times \text{plasma VA})$; $R^2 = 0.15$; $P < 0.01$].

DISCUSSION

DMI and Animal Performance

As expected, Holstein cows had higher DMI and produced more milk and 4% FCM than Jersey cows. During the 2 periods, F₁ cows produced less milk than Holstein cows but similar 4% FCM (Table 3). Previous studies reported similar results for Holsteins and Jerseys. For example, Beaulieu and Palmquist (1995) reported higher DMI, milk production, and 4% FCM in Holstein cows compared with Jersey cows under a TMR system. Additionally, Rastani et al. (2001) reported higher milk production for Holsteins under a TMR system, whereas

White et al. (2001) recorded higher milk production for Holsteins in both pasture and TMR systems compared with Jerseys.

In the current study, milk fat and protein content were higher for Jersey cows, intermediate for F₁ cows, and lower for Holstein cows (Table 3). This is consistent with other studies comparing Holsteins and Jerseys that have reported similar results (Beaulieu and Palmquist, 1995; Mackle et al., 1996; Rastani et al., 2001; White et al., 2001).

Fatty Acid Intake, Milk, and Plasma Fatty Acid Composition

Diet is acknowledged to be the major factor affecting the PUFA content of milk (Chilliard et al., 2001; Khanal and Olson, 2004), with concentrations typically higher under pasture compared with grain-based production systems. Additionally, agronomical factors such as plant growth phase can affect constituent fatty acid composition and thus the milk concentration of FA of cows grazing pasture (Palladino et al., 2009). In Ireland, pastures typically undergo significant agronomical change from June to July as intermediate and late heading perennial ryegrass cultivars (dominant) undergo inflorescence (July). In the initial design of the current study, greater changes were expected in pasture quality than finally materialized; this was most likely caused by atypical weather conditions during the 2 periods employed in the study.

To the knowledge of the authors, no previous published study compares 2 breeds and their F₁ hybrid in terms of FA milk content. In the present study, although

Table 6. Effect of breed on plasma fatty acid composition

Item, %	Breed				Significance ²		
	Holstein-Friesian	Jersey × Holstein	Jersey	SED ¹	Breed	Period	Breed × period
C14:0	1.6	1.7	1.3	0.24	NS	NS	NS
<i>iso</i> -C15:0	0.5 ^{ab}	0.7 ^a	0.3 ^b	0.17	*	**	NS
<i>anteiso</i> -C15:0	2.1	1.9	1.7	0.21	NS	†	NS
C15:0	1.6 ^a	1.2 ^{ab}	1.0 ^b	0.18	*	NS	NS
C16:0	17.5	16.4	17.5	0.55	†	NS	NS
C16:1	6.5	6.4	5.6	0.56	NS	NS	NS
C17:0	1.2	1.4	0.7	0.34	NS	NS	NS
C18:0	17.5	18.2	18.5	0.50	NS	**	NS
<i>cis</i> -9 C18:1	11.1	11.0	12.3	0.58	†	†	NS
<i>trans</i> -11 C18:1 (vaccenic acid)	2.1	1.5	2.2	0.34	NS	NS	*
<i>cis</i> -9, <i>cis</i> -12 C18:2 n-6 (linoleic acid)	20.4	20.5	20.3	0.47	NS	*	NS
<i>cis</i> -9, <i>trans</i> -11 C18:2 (conjugated linoleic acid) ³	—	—	—	—	—	—	—
C18:3 n-3 (linolenic acid)	16.0	16.8	16.7	0.62	NS	*	NS
C20:4 n-6	0.8	0.8	0.6	0.19	NS	NS	NS

^{a,b}Means within a row with different superscripts differ ($P < 0.05$).

¹Standard error of the difference.

²† $P < 0.10$; * $P < 0.05$; ** $P < 0.01$.

³Conjugated linoleic acid was not detected in most of the samples, and there was on average less than 0.2% across all treatments.

cows grazed the same pasture, given the recorded differences in DMI, the intake of PUFA precursors differed among breeds (Table 3). No differences in milk were found for LNA (the main FA in the diet), CLA, and VA, which are the main FA involved in the biohydrogenation process in the rumen and precursors of the main milk PUFA (Jenkins, 1993), from a human health perspective. Furthermore, no relationship was found between the intake of precursors and the FA composition of milk. However, some differences were found in milk FA that are likely to be a function of breed effects. For example, in agreement with previous reports (Drackley et al., 2001), C16:0 was higher for Jersey cows (and also for Jersey $\times$ Holstein cows) and *cis*-9 C18:1 was higher for Holstein cows (intermediate for Jersey $\times$ Holstein cows). However, other authors have found contrasting results. White et al. (2001) recorded higher content of *cis*-9 C18:1 in Holstein cows but did not detect differences in C16:0. Beaulieu and Palmquist (1995) also found higher concentration of *cis*-9 C18:1 in Holstein cows but also higher content of C16:0. Only Soyeurt et al. (2006) found higher content of *cis*-9 C18:1 in Jersey cows. The greater content of C16:0 in milk from Jersey cows was manifested in a higher content of saturated FA, which is in agreement with previous studies (Soyeurt et al., 2006), a lower unsaturated FA:saturated FA ratio, and in a higher content of medium-chain FA (also for Jersey $\times$ Holstein cows). The lack of agreement between studies may be related to differences in diets used across experiments.

There was no effect of cow breed on milk concentration of either LNA or n-3 PUFA. However, n-3:n-6 ratio was lower for Holstein cows because of a higher content of LA and n-6 FA. Drackley et al. (2001) reported that LA tended to be higher and LNA significantly higher for Holstein cows compared with Jersey cows. In contrast, Soyeurt et al. (2006) found that Jersey cows had more milk LA than Holsteins. Beaulieu and Palmquist (1995) did not find differences between breeds for LA, but LNA was higher for Holstein cows in their study. Therefore, it seems that concentrations of both LNA and LA in milk are more likely to be affected by diet rather than breed.

The major source of CLA in milk is through the conversion of VA into CLA via the actions of the enzyme Δ^9 -desaturase (Piperova et al., 2002; Lock and Garnsworthy, 2003). In the current study, there was a strong relationship between CLA and VA in milk ($R^2 = 0.79$). It is known that significant genetic variation exists for the concentration of certain fatty acids in milk, and this is most likely a function of differential expression of genes coding for enzymes catalyzing FA synthesis within the mammary gland (Soyeurt et al., 2008; Mele et al., 2009). For example, previous studies

have shown differences in the activity of the Δ^9 -desaturase enzyme between different breeds and between animals within breed (Kelsey et al., 2003; Soyeurt et al., 2008). Lock and Garnsworthy (2003) suggested that the best indicator of the Δ^9 -desaturase activity is the ratio C14:1/(C14:0 + C14:1) because these FA are produced de novo in mammary gland tissue and thus confounding effects from diet-derived, preformed FA is avoided. In the present study, Holstein cows had the highest estimated Δ^9 -desaturase activity because of a higher content of C14:1. Despite this, no statistical differences were found for milk concentration of CLA even though Holstein cows had numerically higher CLA content. The small differences between breeds is in agreement with previous studies showing little or no differences in milk CLA content across breeds; this effect was partially explained by the high degree of variation between individual animals within breed and is consistent with other studies (Lawless et al., 1999; White et al., 2001). Although the number of cows in this trial seems to be small, it is enough to detect differences on the order of 30% with 80% power (Berndtson, 1991). White et al. (2001) found higher content of milk CLA in Holstein cows compared with Jersey cows. In agreement, Soyeurt et al. (2008) found Jersey cows to have lower Δ^9 -desaturase indices. Nevertheless, Soyeurt et al. (2006) did not find differences in estimated Δ^9 -desaturase activity across 7 breeds (including Jersey and Holstein), although milk CLA content was not reported in this study. In the current study, milk CLA content ranged from 15.0 to 17.2 g/kg of total FA between breeds, whereas milk CLA ranged from 4.3 to 34.1 g/kg of total FA between animals (CV = 0.40) and estimated Δ^9 -desaturase activity varied from 0.05 to 0.14. Lawless et al. (1999) reported similar ranges across breeds and animals for CLA content, whereas Kelsey et al. (2003) found similar estimated Δ^9 -desaturase activity (calculated from C14:1). Other authors also found differences in CLA and estimated Δ^9 -desaturase activity between individual animals (Peterson et al., 2002). Moreover, Kelly et al. (1998) noted that higher estimated Δ^9 -desaturase activity occurs under grazing conditions compared with TMR systems. In agreement, from a review of the literature, we estimated the coefficient of variation of milk CLA content to range from 0.25 (Kelly et al., 1998; Kelsey et al., 2003) under TMR or supplemented grazing systems to 0.50 under an exclusively grazing situation (Lawless et al., 1999). Pasture is acknowledged as the best substrate for de novo CLA synthesis as a consequence of higher accumulation of VA following extensive ruminal hydrogenation of both LA and LNA (Dewhurst et al., 2006). Therefore, animals should have been able to express their genetic potential for CLA synthesis under

the conditions employed in our study. Although breed effects were not evident, the high interanimal variability suggests that genetic selection for high milk CLA may be possible. In fact, Schennink et al. (2008) and Soy-eurt et al. (2008) estimated heritability values of 0.45 ± 0.09 and 0.20 ± 0.018 , respectively, for the Δ^9 -desaturase indices calculated from C14:1. Nevertheless, the interpretation of these indices must be carried out with caution because previous studies noted that there was no relationship between Δ^9 -desaturase indices and the mRNA expression of the stearoyl-CoA desaturase (SCD) enzyme, which introduces the double bond in Δ^9 position of C14:0, C16:0, and C18:0 (Bionaz and Loor, 2008; Kgwatalala et al., 2009). This mismatch is likely because mRNA transcription does not always result in functional protein synthesis. Despite this, authors have reported differences in SCD expression across breeds that confirm the importance of genetic regulation of FA composition (Ohsaki et al., 2007) that involves SCD but also other genes (Taniguchi et al., 2004).

Estimation of heterosis showed that the F₁ hybrid had lower milk content of VA (−10.2%), LA (−13.2%), and CLA (−8.5%) compared with the mid parent average (Holstein and Jersey). From these results, it seems that there is no advantage from heterosis to enhancing the composition of human health-promoting FA in milk, at least within the breeds compared here.

Only VA in plasma was detected as a statistically significant predictor of VA and CLA in milk ($R^2 = 0.20$ and 0.15 for VA and CLA, respectively), although the biological significance of such a poor relationship is questionable. For instance, plasma C16:0 tended to be higher in Holstein and Jersey cows, but Holstein cows had the lowest C16:0 content in milk (Table 5). A similar pattern was recorded for *cis*-9 C18:1, which tended to be higher for Jersey cows in plasma samples but was lower in milk. Doreau et al. (2007) concluded that plasma FA profile was remotely linked to duodenal flows and, as a consequence, plasma FA profile may not be a good indicator of FA uptake or FA concentration in milk. Loor et al. (2005) found differences for most of the plasma FA measured across the treatments employed (Holstein dairy cows offered sunflower oil, linseed oil, or fish oil), but also found some discrepancies between plasma FA and milk FA profile. Therefore, it seems that plasma FA profile is not a good indicator of FA uptake from digestive system and supply to mammary gland in lactating dairy cows and is reflective not only of FA absorbed but also of those released following tissue mobilization.

CONCLUSIONS

There were no differences among breeds for VA, CLA, or LNA (the most important n-3 milk FA in the present

study) in grazing dairy cows. Holstein cows had higher contents of *cis*-9 C18:1 and LA. Nevertheless, large variation between individual animals within breed type was observed for CLA and estimated Δ^9 -desaturase activity. Additionally, we did not observe any evidence for positive heterotic effects on the content of beneficial FA in milk (VA, CLA, and LNA) when cows grazed a high quality pasture. Furthermore, plasma FA profile was found not to adequately reflect differences in milk FA composition. In conclusion, differences between breeds in milk FA content seem to be of little practical importance when cows graze high quality pastures as in the current study. However, the large variation found between individual animals, together with moderate published heritability values for both PUFA and estimates of Δ^9 -desaturase activity, indicates the potential for selecting, at least within breed, for milk with improved nutraceutical content.

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