A comparison between Holstein-Friesian and Jersey dairy cows and their F₁ cross with regard to milk yield, somatic cell score, mastitis, and milking characteristics under grazing conditions

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ABSTRACT

The key objectives of this study were to investigate differences in milking characteristics and udder health between Holstein-Friesian (HF), Jersey (J), and Jersey × Holstein-Friesian (F₁) cows and to determine possible associations between milking characteristics and udder health. Records were available from 329 lactations (162 cows): 65 HF, 48 J, and 49 F₁. Data included lactation mean milk yield, somatic cell score (SCS), incidence of mastitis, average milk flow (AMF), peak milk flow (PMF), and milking duration (MD). Breed group had a significant effect on milk yield and was higher with the HF cows (18.0 kg/d) compared with the J cows (14.2 kg/d). Udder health (SCS and incidence of mastitis at least once during lactation) were similar across the breed groups. Average milk flow was greater with the HF cows (1.36 kg/min) compared with the J cows (1.09 kg/min). Peak milk flow also tended to greater with the HF cows. No difference in MD was observed between the breed groups. The performance of the F₁ cows tended to be similar to the mid-parent (breed) mean for udder health and MD, but heterosis was evident for milk yield, AMF, and PMF. Correlations examined showed that phenotypic milk yield was negatively associated with SCS. Increased milk yield was synonymous with increased AMF, PMF, and MD. Correlations between SCS and milking characteristics were weak. Correlations also showed that cows with low AMF and PMF had extended MD. Therefore, no difference in udder health was observed between HF, J, or F₁ cows. The fact that higher yielding animals exhibit faster milking speeds was confirmed; however, no difference in MD was observed between the breed groups. Such findings indicate that regularity in the milking process will be maintained within mixed-breed herds.

Key words: Jersey, crossbreeding, udder health, milking characteristic

INTRODUCTION

Apart from lameness and reproductive inefficiency, suboptimal udder health is a key contributor to involuntary culling on commercial dairy farms. Inferior udder health results in economic losses to both dairy farmers and milk processors, depressing milk yield (Kelly, 2009) and increasing costs (Huijps et al., 2008). Mastitis can also affect product shelf life (Barbano et al., 2006) and cheese making properties (Ma et al., 2000). Somatic cell count is a key measure employed by processors to determine milk quality. It provides a reflection of the health status of the mammary gland (Schukken et al., 2003) and brings to light the prevalence of clinical and subclinical mastitis in dairy herds. In Ireland, milk pricing is tiered based on monthly arithmetic mean bulk SCC, with penalties imposed on milk with high SCC. More recently, some processors, as an incentive to improve milk quality, have introduced bonus schemes for herds achieving bulk SCC of 200,000 cells/mL or less (Begley, 2008).

Breed differences for mastitis incidence and SCC between Holstein (**H**) and Jersey (**J**) cows have been reported previously. A New Zealand study by Berry et al. (2007) reported higher SCS for J cows compared with Holstein-Friesian (**HF**) cows. Similar findings were reported by Sewalem et al. (2006). Washburn et al. (2002) reported that J cows had a lower incidence of mastitis but similar SCC compared with H cows. A decrease in additive genetic merit for functional traits, particularly fertility and health, within the H population has sparked global interest in crossbreeding dairy cattle (Hansen, 2006). Interest in crossbreeding, particularly with the J breed, is driven by the potential of improved profitability (Lopez-Villalobos et al., 2000), fertility (Auldist et al., 2007), and longevity (Harris et al., 1996) in commercial dairy herds. Previous studies have documented the effects of crossbreeding on SCS. Van Raden and Sanders (2003) reported a small but positive (unfavorable) estimate of heterosis for SCS with H, Guernsey, and J cows and their crosses. Begley (2008) found favorable improvements in udder health

Received October 2, 2009.

Accepted March 1, 2010.

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with Norwegian Red $\times$ HF cows. However, neither Walsh et al. (2007) nor Begley (2008) reported a heterosis effect for SCS.

Milking characteristics are important functional traits of dairy cattle. Milkability, which Rovai et al. (2007) defined as the adaptation and performance of dairy animals to the machine milking process, is influenced by production level, udder morphology, milking fractions, and kinetics. A decrease in milking duration (MD) could potentially decrease milking labor time, which represents an important expense in the harvest of milk (Cecchinato et al., 2007). However, fast-milking cows may be more susceptible to mastitis (Zwald et al., 2005), thus having a negative relationship with udder health. Rupp and Boichard (1999) found MD to be positively associated with SCS but not with higher incidence of mastitis. A within-strain HF comparison study conducted by McCarthy et al. (2007) reported greater SCS coupled with a faster peak milk flow for New Zealand HF cows compared with high production and high durability North American HF cows. Walsh et al. (2007) examined differences between breeds with regard to milking characteristics and udder health and reported that udder health was superior with the Norwegian Red and Montbeliarde breeds compared with Normande, Montbeliarde $\times$ HF, and Normande $\times$ HF breeds. In that study, whereas differences in milk yield, average milk flow (AMF), and peak milk flow (PMF) were observed, no difference in MD was reported between the breed groups. Beck et al. (1951) previously reported no difference in milking speed between the J and HF breeds. However, to our knowledge, no study has previously investigated the effect of crossing J and HF breeds with regard to milking characteristics.

The objectives of this study were to investigate differences in milking characteristics and udder health between HF, J, and F_1 cows as well as possible associations between milking characteristics and udder health.

MATERIALS AND METHODS

Data were generated at the Ballydague research farm part of the Teagasc Moorepark Dairy Production Research Center (Fermoy, Co. Cork, Ireland). The experiment commenced in January 2006 and compared the HF, J, and F_1 cows under Irish grass-based conditions. For this study, 3 yr of data (2006–2008) were available. All cows were primiparous in yr 1. In yr 2, 32% of the animals were in parity 1, with the remainder in parity 2. In yr 3, 22, 26, and 52% were of first, second, and third parity, respectively. Records were available from 329 lactations (112 HF, 106 J, and 111 F_1) from 162 cows (65 HF, 48 J, and 49 F_1). The HF cows were predominately

of North American HF decent. The J cows were sired by bulls of New Zealand and Danish origin, with the F_1 cows generated by mating J bulls to HF cows. A total of 16 HF and 18 J sires were represented. The weighted mean predicted transmitting abilities and standard deviations for the HF sires used across the study were +145 kg (62.7), +11 kg (5.6), +8 kg (2.7), +0.09% (0.12), +0.06% (0.04), and +0.02 (0.096) for milk yield, fat yield, protein yield, fat concentration, protein concentration, and SCC, respectively (ICBF, 2009). Respective predicted transmitting abilities of the J sires were –344 kg (108), +15 kg (7), 3 kg (5), +0.62% (0.13), +0.28% (0.06), and +0.05 (0.077), with 8 of the 18 J sires common to both the J and F_1 breeds. The sires of both breeds used were commonly available in Ireland.

Experimental Design and Cow Management

Cows grazed as a single herd for the first 2 yr of the study and in 3 separate treatment groups in yr 3. In mid April of yr 1, cows were randomized across 2 grass-based feeding systems: low concentrate (LC) and high concentrate (HC). Cows within breed group were randomly assigned to a treatment based on calving date, milk solids yield, and BW. Concentrate supplementation corresponded to 658 and 1,072 kg of DM/cow for the LC and HC groups, respectively. In yr 2, all cows were managed in a similar fashion to LC in yr 1, but concentrate supplementation averaged 240 kg of DM/cow. The difference in concentrate allowances between yr 1 and 2 was attributable to a prolonged period of soil moisture deficit on the farm in yr 1. Grass production, predominately perennial ryegrass (*Lolium perenne*), was measured at the Moorepark Research Center using 650 kg of N/ha (Figure 1) as described by Corrall and Fenlon (1978). Total grass production in yr 1 averaged 12.7 tons of DM/ha compared with 14.7 and 15.5 tons of DM/ha for yr 2 and 3, respectively. In yr 3, cows were randomly assigned within breed to a 3 $\times$ 3 factorial experiment comparing the HF, J, and F_1 cows under 3 stocking rate systems. Total concentrate supplementation amounted to 352 kg of DM/cow. Concentrate supplementation was similar across the treatment groups. The HF and F_1 animals were stocked at 2.5, 2.75, and 3.0 cows/ha for the low, medium, and high stocking rate treatments, respectively. The J cows were stocked at 2.75, 3.0, and 3.25 cows/ha, respectively. Treatments were applied based on differences in DMI, obtained by Prendiville et al. (2009). Concentrate ingredient composition was similar for each year of the study: citrus pulp, 300 g/kg; barley, 237 g/kg; corn (*Zea mays*) gluten feed, 213 g/kg; soybean meal, 140 g/kg; vegetable fat, 30 g/kg; caned molasses, 50 g/kg; and minerals, 30 g/kg.

Figure 1. Daily herbage growth rates at Moorepark Dairy Production Research Centre (Fermoy, Co. Cork, Ireland): 1997–2006 and 2007.

Cows were turned out to grass each year from early February until mid November and were housed during the winter period. An 8-wk dry period was deemed sufficient for multiparous cows, with primiparous animals given a 10-wk dry period. All animals were offered grass silage *ad libitum* with dry cow minerals at a rate of 100 g/cow per day during the winter months. A detailed outline of the wintering facilities and winter management is presented by O'Driscoll et al. (2008). Briefly, animals were housed either in a conventional indoor house or on 1 of 3 types of out-wintering pad (OWP): an uncovered OWP, a covered OWP (both with a concrete feed face), or an uncovered OWP with a self-feed silage pit. In spring, on-off grazing was practiced during periods of inclement weather (Kennedy et al., 2009). During the critical periods, February to May and September to November, calcined magnesite (Nutribio, Cork, Ireland) was dusted on paddocks to prevent magnesium deficiency. Cows were milked twice daily at 0700 and 1545 h, with concentrates offered in 2 equal feeds during each milking.

Cow Measurements and Milking Procedure

Milk yield was recorded daily using electronic milk meters (Dairymaster, Causeway, Co. Kerry, Ireland). Somatic cell count was determined biweekly from morning samples using a Bentley Somacount 300

(Bentley Instruments Inc., Chaska, MN). Incidences of clinical mastitis, defined by inflammation of the udder and presence of clots, were recorded throughout lactation. Cows were milked twice daily at 0700 and 1545 h. Milking characteristics were determined as described by Walsh et al. (2007). Briefly, milking was carried out at a 48-kPa vacuum, with a pulsation ratio of 65:35 at a rate of 60 cycles/min. Milk duration and milk flow (kg/min) were recorded daily using the aforementioned electronic milk meters. Milking duration was defined as the time from cluster attachment to cluster removal. To prevent overmilking, the clusters were automatically removed when a minimum of 4 min had elapsed and milk flow was below 0.2 kg/min.

Data Analyses

The effect of feeding treatments was not of direct interest in this study. However, for the purpose of statistical analysis, cows were assigned to 1 of 4 feeding treatments as deemed appropriate. Feeding treatment 1 was assigned to cows offered the HC treatment in yr 1. Feeding treatment 2 was assigned to animals on the LC treatment in yr 1, all animals in yr 2, and to cows on the medium stocking rate treatment in yr 3. Feeding treatment 3 included animals on the high stocking rate treatment in yr 3. Feeding treatment 4 was assigned to

the cows on the low stocking rate treatment in yr 3 of the study.

Data were available from 8,048 test-day records representing 329 lactations from 162 cows for SCC analysis. The natural logarithm of SCC was used to define SCS (Walsh et al., 2007).

Individual milk yield and milking characteristics were recorded for each cow daily throughout lactation, providing a total of 13,446 test-day records. Records between 5 and 305 DIM were included in this analysis. Test-day records containing both a.m. and p.m. milkings were retained for analysis. Milk flow was computed by the milk meter and continuously calculated by measuring the change in weight every 20 s. Maximum flow was the peak of this value. Average milk flow was defined as total daily yield divided by total daily MD. Milk yield, MD, and PMF were determined at each milking. Milking duration was expressed as the sum of the a.m. and p.m. MD. For the purpose of this analysis, the natural logarithm of MD was used. Data editing was per Walsh et al. (2007).

Analysis Over Lactation. Mean SCS records for cow within lactation were used to determine average SCS over lactation. Average milk flow, PMF, and MD were determined weekly and subsequently averaged within lactation. Data were analyzed using PROC MIXED in SAS (version 9.1, SAS Institute Inc., Cary, NC). The linear model included the fixed effects of breed group (HF, J, and F_1), parity, year, and feeding treatment. Calving day of year and lactation length were fitted as continuous covariates. Cow was included as a random effect, with parity included as a repeated effect. Using the Akaike's information criterion, a compound symmetry structure for the residuals was determined as the most appropriate residual covariance structure for repeated measures over time within cows. Breed groups (HF vs. J) and the F_1 vs. the mid-parent mean, the latter providing an estimate of heterosis between the 2 breeds, were compared using orthogonal contrast statements in PROC MIXED.

Stage of Lactation Effect. Lactations were divided into 10 substages: wk 1–4, wk 5–8, wk 9–12, wk 13–16, wk 17–20, wk 21–24, wk 25–28, wk 29–32, wk 33–36, and wk 37–44. Milk yield, SCS, AMF, PMF, and MD were established within each stage and analyzed again using PROC MIXED in SAS. The linear model was similar to that above but also included stage of lactation and the interaction between breed group and stage of lactation.

Clinical Mastitis. The incidence of cows exhibiting clinical mastitis was analyzed using the LOGISTIC procedure in SAS (clinical mastitis = 1 for cows that got mastitis at least once during the study period, otherwise clinical mastitis = 0). A contrast statement

was used to determine the presence of heterosis. The model included the fixed effects of breed group (HF, J, and F_1), parity, year, feeding treatment, and lactation stage. Calving day of year and lactation length were fitted as continuous covariates. The incidence of clinical mastitis through stages of lactation were determined by dividing the lactation into 5 substages: wk 1–5, wk 6–13, wk 14–21, wk 22–29, and wk 30–44. The total incidence of clinical mastitis (number) per cow per year was analyzed using the MIXED procedure of SAS. The linear model included the fixed effects of breed group (HF, J, and F_1), parity, year, and feeding treatment, with calving day of year included as continuous covariate.

Relationships Between Milk Yield, Udder Health, and Milking Characteristics. Associations between mean lactation milk yield, SCS, and milking characteristics were analyzed using the Pearson product-moment rank correlation. Analysis was undertaken using the PROC CORR procedure in SAS while adjusting for breed group, lactation, feeding treatment, year, and calving day of year.

RESULTS

Breed Effect on Lactation Averages

Milk yield was greater for the HF cows compared with the J cows ($P < 0.001$), whereas SCS was similar for the 2 breeds (Table 1). A total of 83 mastitis cases from 53 cows were recorded over the 3-yr period: 22, 17, and 14 HF, J, and F_1 cows, respectively. The incidence of mastitis was similar for the HF and J breed groups (16.5 and 17.6%, respectively). Total incidences of mastitis (accounting for repeated incidences) were higher ($P < 0.05$) with the J cows (1.54) compared with the HF cows (1.24). Average milk flow was greater ($P < 0.001$) with the HF cows compared with the J cows, with PMF tending ($P = 0.067$) to be higher with the HF cows. Milking duration was similar across the breed groups.

The F_1 breed had a greater milk yield ($P < 0.001$), AMF ($P < 0.01$), and PMF ($P = 0.05$) compared with the mean of the parent breeds. The mean values of the parent breeds were 16.0 kg/d, 1.23 kg/min, and 2.79 kg/min for milk yield, AMF, and PMF, respectively. This corresponded to heterosis estimates of +1.0 kg (+5.8%), +0.10 kg/min (+7.9%), and +0.32 kg/min (+10.3%) for milk yield, AMF, and PMF, respectively. Somatic cell score, incidence of mastitis, and MD of the F_1 cows were similar to the mid-parent mean.

Interaction Between Breed and Stage of Lactation

Peak milk yield was attained at stage 2 (wk 5–8) of lactation for all breed groups (23.8, 19.2, and 21.9 kg/d

Table 1. Effect of breed on milk yield, SCS, milkability, and incidence of mastitis

Item ¹	Breed group ²			HF vs. J		F ₁ vs. parent mean	
	HF	J	F ₁	SEM ³	P-value	SEM	P-value
Milk yield (kg/d)	18.0	14.2	17.1	0.29	<0.001	0.26	<0.001
SCS ⁴	10.6 (114)	10.8 (119)	10.7 (132)	0.15	NS	0.13	NS
AMF (kg/min)	1.36	1.09	1.33	0.037	<0.001	0.033	<0.01
PMF (kg/min)	2.93	2.65	3.11	0.154	0.067	0.140	<0.05
MD (log s/d)	6.64	6.62	6.62	0.024	NS	0.023	NS
Mastitis (%)	16.5	17.6	14.1	5.49	NS	4.70	NS

¹AMF = average milk flow; PMF = peak milk flow; MD = milking duration.

²HF = Holstein-Friesian; J = Jersey; F₁ = Jersey × Holstein-Friesian.

³Pooled SEM.

⁴Corresponding SCC ($\times 10^3$ cells/mL) in parentheses.

for the HF, J, and F₁ cows, respectively) and declined gradually until the end of lactation (Figure 2). Average daily milk yield was lower ($P < 0.001$) for the J cows compared with the HF and F₁ cows throughout lactation. Milk yield was greater with the HF cows compared with the F₁ cows throughout lactation, with the exception of late lactation (stage 9), where it was similar for the breed groups.

Conversely, SCS was lowest from stages 2 to 4 (wk 9–16) of lactation and subsequently increased until the end of lactation. Somatic cell score for the J cows was similar to that of the HF and F₁ cows throughout lactation. Somatic cell score was lower ($P < 0.05$) in late lactation (>37 wk of lactation) for the HF cows compared with the F₁ cows. Incidence of mastitis across the breed groups was highest (43% of total) in stage 1 of lactation, 19% in stage 2 of lactation, lowest during mid lactation (10 and 8% in stages 3 and 4, respectively), and 20% in late lactation (stage 5).

Average milk flow was highest for all breeds in stages 2 and 3 (wk 5–12) of lactation and declined gradually until the end of lactation (Figure 3). The HF and F₁ cows had a greater AMF than the J cows across all stages of lactation ($P < 0.001$). Average milk flow was similar for the HF and F₁ cows with the exception of stage 10 (>37 wk) of lactation, which was greater ($P < 0.01$) for the HF cows compared with the F₁ cows.

Peak milk flow was similar for the HF and J cows with the exception of late lactation (>33 wk), when PMF was greater for the HF cows compared with the J cows. Peak milk flow tended to be higher for the F₁ cows compared with the HF cows in early and mid lactation but was similar in late lactation. Throughout lactation, PMF of the F₁ cows was higher than that of the J cows ($P < 0.05$).

Average MD was highest for all breeds in early lactation, followed by a decline until the end of lactation. In early lactation (<17 wk of lactation), milking duration was longest for the HF cows compared with the J and

F₁ cows ($P < 0.05$). Thereafter milking duration was similar for all breed groups. Milking duration was not different between the J and F₁ cows throughout lactation.

Associations Between Milk Yield, Udder Health, and Milking Characteristics

Weak but significant ($P < 0.001$) negative correlations were observed between mean daily milk yield and mean lactation SCS (Table 2). Mean daily milk yield was strongly positively correlated with AMF ($P < 0.001$). Modest positive associations were also observed between mean daily milk yield, PMF, and mean MD ($P < 0.001$). Weak negative correlations ($P < 0.001$) were observed between SCS and milking characteristics. Average milk flow was strongly correlated to PMF ($P < 0.001$). Mean MD was longer for cows with lower AMF ($P < 0.001$) and PMF ($P < 0.001$).

DISCUSSION

Breed Differences

Differences in milk production between HF and J cows have been well established (Oldenbroek 1988; Mackle et al., 1996). Despite the difference in milk yield between the HF and J cows, no difference in SCS was observed between the breed groups, which is in disagreement with the work of Berry et al. (2007), a New Zealand study that showed that J cows had a higher SCS compared with HF cows. Similarly, a Canadian study by Sewalem et al. (2006) consisting of approximately 1.9 million H cows and 53,000 J cows reported higher SCC for J cows compared with H cows (212,000 and 167,000 cells/mL, respectively). Consistent with the current study, Washburn et al. (2002) reported similar SCC for H and J cows. However, the results of Washburn et al. (2002) and that of this study are based on the findings

of small sample sizes. The current study shows that the incidence of mastitis was similar for the HF and J cows. Both Washburn et al. (2002) and Berry et al. (2007) also reported that the prevalence of mastitis was higher for H and HF cows compared with J cows. The greater incidence of mastitis in early lactation in this study is consistent with the findings of Hogan et al. (1989), Berry and Meaney (2005), and Barkema et al. (1998).

Results from the current study indicate that weak antagonistic associations between phenotypic mean daily milk yield and mean lactation SCS exist within breed. This indicates that, during lactation, an increase in milk yield is synonymous with a decrease in SCS, suggesting a possible dilution effect (Wicks and Leaver, 2006). Harmon (1994) cited parity and stage of lacta-

tion as major factors that influence SCC. Reneau et al. (1986) and Kelly (2009) reported that monthly SCC is usually the inverse of the lactation curve. Schultz (1977) and Reneau et al. (1986) postulated that the increase in SCC in uninfected quarters in late lactation is the dilution effect. This is further substantiated by Walsh et al. (2007), who reported a decrease in SCS with an increase per 1 kg of milk yield. Such findings are consistent with the results of Mrode et al. (1998), who reported negative phenotypic correlations between milk yield and SCC but positive genetic correlations between milk production and SCC. Both Rupp and Boichard (1999) and Carlén et al. (2004) also reported a positive (undesirable) genetic correlation between milk production and SCS. Emanuelson et al. (1988) reported

Figure 2. Effect of Holstein-Friesian (♦), Jersey (■), and Jersey × Holstein-Friesian (▲) cows on milk yield (kg/d) and SCS over lactation. Vertical bars indicate 1 pooled standard error.

Figure 3. Effect of Holstein-Friesian (♦), Jersey (■), and Jersey × Holstein-Friesian (▲) cows on milking duration (min/d), average milk flow (kg/min), and peak milk flow (kg/min) through lactation. Vertical bars indicate 1 pooled standard error.

Table 2. Associations between milk yield (kg/d), SCS, and milking characteristics¹ obtained through the Pearson product moment rank correlations between lactation means²

Item	SCS	AMF	PMF	MD
Milk yield	-0.14 (<0.001)	0.64 (<0.001)	0.20 (<0.001)	0.18 (<0.001)
SCS		-0.03 (<0.05)	0.09 (<0.001)	-0.09 (<0.001)
AMF			0.68 (<0.001)	-0.62 (<0.001)
PMF				-0.64 (<0.001)

¹AMF = average milk flow (kg/min); PMF = peak milk flow (kg/min); MD = milking duration (log s/d).

²Correlations presented are significantly different from zero.

moderately high genetic correlations between mastitis and SCC. These genetic correlations suggest that selection for an increase in milk production coincides with an increase in SCS and, consequently, mastitis.

The rate of AMF was faster for the HF cows compared with the J cows. This is consistent with the findings of Gandini et al. (2007), who found that H cows had a faster release rate compared with Reggiana cows. Similarly, Walsh et al. (2007) found higher AMF for HF, Norwegian Red, Montbeliarde $\times$ HF, and Normande $\times$ HF breeds compared with Montbeliarde and Normande breeds. Average milk flow in the current study was lower than that reported by McCarthy et al. (2007), Gandini et al. (2007), and Walsh et al. (2007). However, this may be attributable to differences in the breed groups, feeding systems, and age structure across the studies. In the studies of McCarthy et al. (2007) and Walsh et al. (2007), cows were assigned to high concentrate and low concentrate feeding systems throughout the experimental period. Both studies demonstrated that animals offered high concentrate diets had greater AMF and MD as a consequence of the greater yields. Increased parity will also result in a faster rate of flow (Sandrucci et al., 2007). In the current study, 76% of the animals were in either first or second parity, whereas the studies of McCarthy et al. (2007) and Walsh et al. (2007) had an older age structure. Older cows tend to have higher yields (Ray et al., 1992) and longer, more dilated streak canals (McDonald, 1968), thus having a greater milk flow rate (Grindal and Hillerton, 1991). The reduction in AMF through lactation observed in the present study was consistent with the results of Sandrucci et al. (2007) and reflective of the influence of yield through lactation. This supports the findings of Weiss et al. (2004), who documented strong positive associations between milk yield and AMF, substantiated in the current findings by the positive correlation between milk yield and AMF.

Peak milk flow of the HF cows tended to be higher than that of the J cows. This is consistent with the findings of Beck et al. (1951), who reported a maximum rate of flow of 9.3 lb/min (4.2 kg/min) and 7.5 lb/min (3.3 kg/min) for H and J cows, respectively. In agree-

ment with the findings of Walsh et al. (2007), PMF observed in this study was highest in early lactation and declined thereafter. McCarthy et al. (2007) found a greater PMF and SCS for New Zealand HF compared with North American HF strains. Previous studies have reported positive associations between PMF and susceptibility to mastitis (Grindal and Hillerton, 1991), most likely because of a reduction in the tonus of the sphincter muscle in the teat canal (Naito et al., 1964) enabling pathogens to enter the udder. Although such associations were not evident from this study, perhaps differences may have come to light if more mature animals were available. Correlations between milk production and PMF in the current findings are in contrast to the findings of Bagnato et al. (2003), who reported greater milk production for cows with lower PMF. The negative correlations between MD and PMF are consistent with the findings of Sandrucci et al. (2007) and Tancin et al. (2006).

Despite the difference in milk yield and milk flow between the HF and J cows, no difference in MD was observed between the breeds. In fact, in early lactation, MD was greater with the HF cows. Similarly, Beck et al. (1951) reported a faster rate of milk flow for H cows than for J cows but no difference in MD between the H and J cows. In addition, Gandini et al. (2007) reported similar MD for H and Reggiana cows, although the H cows had a greater AMF. Previously, Walsh et al. (2007) showed no effect of breed on MD but found that MD did increase with increased yield. The correlations observed corresponded to an average increase in MD of 1.69 min/unit of milk yield.

In the current study, weak antagonistic correlations between udder health and MD were observed. Walsh et al. (2007) reported a similar finding. Boettcher et al. (1998) reported positive genetic correlations between milking speed and SCS, likely because of faster evacuation of milk from the udder, thus facilitating entry of pathogens into the udder. Although associations between udder health and milking characteristics in the current study were weak, previous studies suggest that milking characteristics could be incorporated into breeding strategies as indicator measures for improving

udder health. Boettcher et al. (1998) proposed 2 indices on udder health that incorporated SCS, milking speed, and udder measurements (fore udder, rear udder, and mammary system composites) and reported that they excelled over the Canadian udder health index in place at that time.

F₁ and Mid-Parent Mean

Currently, there is growing interest in crossbreeding among Irish dairy producers, particularly with the J and Norwegian Red breeds. Functional traits such as health and fertility have been common to selection indices in Scandinavian countries for many years. Therefore, it is not surprising that Begley (2008) reported superior udder health of Norwegian Red cows compared with HF cows and suggested that incorporating the Norwegian Red breed into breeding strategies via crossbreeding could result in improvements to udder health. Much of the interest in crossbreeding with the J breed is fuelled by the suitability of the F_1 to grazing environments, improving reproductive inefficiency within HF herds (Auldist et al., 2007), a need to maximize milk solids production per hectare, and more recently, the introduction of a multicomponent index system of milk payment in Ireland (Shalloo, 2007). Estimates of heterosis for milk yield (Ahlborn-Breier and Hohenboken, 1991) and functional traits (Harris et al., 1996) are generally positive. In the current study a heterosis estimate of 5.8% was obtained for milk yield, similar to that reported by Ahlborn-Breier and Hohenboken (1991) with $J \times HF$ cows.

Begley (2008) reported additive genetic superiority for udder health for the Norwegian Red breed and consequent improvements with the F_1 (Norwegian Red $\times$ HF), but reported no evidence of heterosis. Unlike the Norwegian Red breed, the J breed is not renowned for superior udder health (SCS), as shown by Sewalem et al. (2006) and Berry et al. (2007). It is perhaps not surprising, therefore, that no evidence of heterosis was found in the current study. Heins et al. (2008) reported similar SCS for first-lactation H and F_1 cows. Van Raden and Sanders (2003), on the other hand, have reported low but positive (unfavorable) heterosis estimates for SCS using H, Guernsey, and J cows and their crosses. With this in mind, Van Raden and Sanders (2003) postulated that an increase in milk yield of crossbred animals may increase the stress on the udder, resulting in a small net increase in SCS. Milk flow of the F_1 was faster than that of the mid-parent mean. With the exception of Walsh et al. (2007), the authors of this study are unaware of any other studies estimating heterosis for milking characteristics. Whereas heterosis for AMF corresponded to 6.5 and 8% for the Montbeliarde $\times$ HF

and Normande $\times$ HF breeds, respectively, heterosis was not observed for PMF and MD. However, from a practical perspective, MD was similar with the F_1 to that of the parent breeds. This will ensure consistency during the milking process, a relevant finding for mixed-breed and crossbred herds.

CONCLUSIONS

Results from the current study highlight breed differences for milk yield and milk flow characteristics. No difference in udder health (SCS or incidence of cows presenting with clinical mastitis) was observed between HF, J, or F_1 cows. The fact that higher yielding animals exhibit faster milking speeds was confirmed. However, no difference in MD was observed between the breed groups investigated. Such findings indicate that regularity in the milking process will be maintained within mixed-breed herds, of practical relevance where crossbreeding is the breeding strategy of choice.

ACKNOWLEDGMENTS

The authors acknowledge Jim Grant (Teagasc, Kinsealy, Ireland) for his statistical advice during the preparation of this manuscript. The technical assistance of Noel Byrne and the diligent work of the farm staff at the Ballydague Research Farm (Ballyhooly, Co. Cork, Ireland) are gratefully acknowledged.

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