Genetic and environmental effects on early growth and performance in purebred Holstein, Jersey, and reciprocal crossbred calves

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ABSTRACT

For this designed experiment, Holstein × Holstein ($n = 28$), Jersey × Jersey ($n = 10$), Holstein × Jersey ($n = 15$), and Jersey × Holstein ($n = 15$) bull and heifer calves were compared for body weight (BW), dry matter intake, feed efficiency, hip height, BW gain to 42 and 56 d, and days to weaning from birth to 8 wk. All traits were examined for purebred, maternal, and heterotic genetic effects. Purebred genetic effects significantly favored the Holstein breed for BW, dry matter intake, hip height, and BW gain to 42 and 56 d. Heterotic genetic effects were present for dry matter intake and hip height. Calf sex affected BW and BW gain to 56 d. Our results indicate that early calf growth is influenced primarily by purebred effects favoring the Holstein breed and to a lesser extent heterosis.

Key words: crossbreeding, dairy calf, growth

INTRODUCTION

Crossbreeding in the commercial dairy industry is gaining popularity as producers try to maximize longevity, health, and economic efficiency of cows in their herds (Weigel and Barlass, 2003). Improved understanding of growth and performance of crossbred dairy calves may help producers use crossbreds more efficiently in commercial dairy systems. The economic benefits of using crossbreds in dairy systems are well documented (Touchberry, 1992; McAllister et al., 1994; Lesmeister et al., 2000; Lopez-Villalobos et al., 2000; Sørensen et al., 2008; Buckley et al., 2014), as are growth and performance traits for pureline and crossline animals (Batra and Touchberry, 1974; McDowell, 1982; Lee et al., 1988; Heins et al., 2008; Olson et al., 2009). A potential economic benefit of crossbreeding is earlier weaning

because it allows producers to decrease labor costs and may aid in lowering feed costs (Davis and Drackley, 1998; Kehoe et al., 2007). Growth rates influence time of weaning, age at first calving (Heinrichs and Swartz, 1990; Cady and Smith, 1996), and subsequent milk production (Virtala et al., 1996). Whereas many of these studies focused on growth and performance traits for calves 3 mo of age and older, little is known about the very early growth and performance of purebred calves compared with crossbred calves. The objectives of this designed experiment were to compare growth and performance traits of purebred Jersey and Holstein calves with Holstein × Jersey and Jersey × Holstein F_1 crossbred calves from birth to 8 wk and estimate the purebred, maternal, and heterotic genetic effects on those traits.

MATERIALS AND METHODS

Animals

From January 2003 to January 2004, purebred Holstein and Jersey nulliparous heifers and primiparous and multiparous cows from the University of Kentucky research dairy herd were inseminated using heterospermic semen (Select Sires Inc., Plain City, OH) as part of a large, multiherd designed experiment (Olson et al., 2009). Straw composition was 50% Holstein semen and 50% Jersey semen from 4 Holstein and 4 Jersey bulls (Table 1), allowing for equal opportunity of fertilization (Kasimanickam et al., 2006). Holstein and Jersey bulls were chosen with the following criteria: (a) they were alive and producing semen; (b) the 4 sires chosen from each breed were in the top 50% of active AI sires for net merit at the time of selection in 2001, endeavoring to choose one bull each from the 90th, 80th, 70th, and 60th rank percentiles; and (c) the bulls chosen should be as unrelated to each other as was possible so that inbreeding in the pure genetic lines would not favor either breed. Matings were made to avoid close relationships between the purebred bulls and the purebred Holstein and Jersey cows to which they were mated. Females were randomly assigned to be inseminated with 1 of

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the 16 heterospermic combinations, except for avoidance of significant inbreeding of potential offspring. Approximately 1 wk before expected parturition, or as indicated by a drop in serum protein concentration and visual appraisal, a Foal Alert system (Foalert Inc., Acworth, GA) transmitter was attached to the vulva of each cow. The Foal Alert system notified researchers of the imminent birth of a calf. From November 2003 to December 2004, 68 bull and heifer calves born to cows inseminated using heterospermic semen were used with genetic groups representing purebred Holstein ($n = 28$, representing all 4 Holstein sires), Holstein $\times$ Jersey ($n = 15$, representing all 4 Holstein sires), Jersey $\times$ Holstein ($n = 15$, representing all 4 Jersey sires), and purebred Jersey ($n = 10$, representing 3 Jersey sires). The number of progeny by sire (Table 1) showed that all 4 Holstein sires had progeny in both the purebred Holstein and Holstein $\times$ Jersey groups and all 4 Jersey sires had progeny in the Jersey $\times$ Holstein group. Three Jersey sires had progeny in the purebred Jersey group. Only one Jersey sire had a single progeny, that being in the Jersey $\times$ Holstein group.

All experimental procedures followed University of Kentucky Institutional Animal Care and Use Committee guidelines. Newborn calves were removed from their dam immediately after birth to prevent maternal suckling and were weighed. To determine amount of colostrum needed, BW was recorded and rounded to the nearest 4.5-kg increment. Colostrum was fed at 5% of rounded BW within 3 h of birth. The colostrum used for this study was collected from all herd females that calved before and during the trial and tested for quality using a colostrometer. Colostrum with specific gravity greater than 60 mg of Ig per milliliter was used to create pooled lots. Lots of pooled colostrum ($n = 6$) were frozen at -20°C until feeding, at which time

colostrum was warmed to at least 26.7°C . Twelve hours later, a second feeding of colostrum was again given at 5% of rounded birth BW. Because individual calves were fed from pooled lots of colostrum without regard to breed of contributing female, the effect of quality of colostrum on the calf performance traits measured did not reflect the maternal genetic differences of Holstein and Jersey dams.

Beginning at 24 h of age, calves were moved to individual hutches and fed whole milk at 5% of rounded BW twice daily. Calves leaving greater than 0.47 L of colostrum or milk were fed via an esophageal feeder. Water and a starter ration were provided beginning at 3 d of age. Calves were weighed weekly, and the amount of milk fed daily was adjusted to 10% of calf rounded BW through 3 wk of age. Calf weaning occurred once intake of starter ration was equal to or greater than 1% of BW for 3 d consecutively, and days to weaning (DWN) was recorded as the age of the calf in days when this occurred.

Fecal scores were based on the method of Larson et al. (1977) and obtained daily through 6 wk to determine general level of health. Scores were ranked on a 1-to-4 scale with normal receiving a score of 1 and severe scouring a 4. When fecal material was not present on a given day, an average was taken of the preceding and following days. Calves with fecal scores of 3 were fed electrolytes once daily (1.9 L), whereas calves with fecal scores of 4 were fed electrolytes twice daily (Merrick's Inc., Middleton, WI). Normal milk feeding continued during electrolyte supplementation.

Sample Collection and Analysis

Weekly BW (kg), milk intake (kg), and grain intake (kg) were measured through 8 wk. Dry matter was calculated as 13% of milk intake and 89% of grain intake. Growth measures BW gain to 42 and 56 d (**G42** and **G56**, respectively), weekly DMI and feed efficiency (**FE**) were calculated. Feed efficiency was defined as weekly BW gain divided by weekly DMI. Hip heights (cm) were obtained within 48 h of birth and again at 6 wk of age.

Statistical Analysis

Data were analyzed as a randomized incomplete split-plot design (Littell et al., 1996). All analyses were conducted using the PROC GLM or MIXED procedures in SAS (v. 9.0, SAS Institute Inc., Cary, NC). Dependent variables were analyzed using PROC MIXED when repeated measures for a response variable were present (e.g., BW, DMI, FE, and hip height). For mixed models, calf represented the random effect and day was

Table 1. List of sires used in heterospermic semen combinations and the resulting number of progeny for each breed group

Breed and designation	Sire short name ¹	No. of progeny for each sire ²			
		HH	HJ	JH	JJ
Holstein					
H1	Jasper	9	3	0	0
H2	Cooper	4	6	0	0
H3	Breton	1	2	0	0
H4	Dane	14	4	0	0
Jersey					
J1	Freedom	0	0	6	4
J2	Paramount	0	0	1	0
J3	Parade	0	0	3	1
J4	Elevation	0	0	5	5

¹As given in Olson et al. (2009; Table 4).

²HH = purebred Holstein; HJ = Holstein $\times$ Jersey; JH = Jersey $\times$ Holstein; JJ = purebred Jersey.

Table 2. Coefficients used to estimate genetic effects

Genetic effect	Genetic group ¹			
	HH	HJ	JH	JJ
Purebred	1.0	0.5	0.5	0.0
Heterosis	0.0	1.0	1.0	0.0
Maternal	1.0	0.0	1.0	0.0

¹HH = purebred Holstein; HJ = Holstein × Jersey; JH = Jersey × Holstein; JJ = purebred Jersey.

the repeated measure. Covariance structure was determined based on goodness-of-fit criteria: Akaike information criterion and Schwarz Bayesian criterion. The Kenward-Rogers degree-of-freedom method was used to determine appropriate degrees of freedom and mean squares to use in tests of significance of fixed effects in the analyses of variables with repeated measures.

For BW, DMI, FE, and hip height, the repeated-measures mixed model included as fixed effects sex (male or female) + parity of dam (first parity or second or greater) + colostrum lot (lots 1 to 6) + day of age at sample collection (d 7, 14, 21, 28, 35, 42, 49, and 56) + purebred genetic effect + heterotic genetic effect + maternal genetic effect + the six 2-factor interactions among the 4 nongenetic fixed effects + covariates (dystocia score of dam's calving, beginning BW, DWN, and DMI; as appropriate).

For G42, G56, and DWN, the model included as fixed effects sex + parity of dam + colostrum lot + purebred genetic effect + heterotic genetic effect + maternal genetic effect + the three 2-factor interactions among the nongenetic fixed effects + covariates (dystocia score of dam's calving, beginning BW, DWN and DMI; as appropriate).

Season was also recorded but not included in the model as a result of confounding with genetic groups and pooled colostrum lots. Dystocia score of the calving; DMI; DWN, beginning BW, or both were included as covariates in appropriate models but were removed from the model if nonsignificant ($P > 0.10$). All 2-way interactions between fixed effects were tested and removed from the model when nonsignificant ($P > 0.10$).

Coefficients for the genetic effects are presented in Table 2. Coefficients represent the percentage of Holstein genes in the calf (purebred genetic effect), percentage of Holstein genes in the dam of the calves (maternal genetic effect), and percentage of expected heterosis in the calf (heterotic genetic effect). Because there were only 2 purebred genetic groups with 0% expected heterosis and the 2 reciprocal F_1 genetic groups each expressing 100% heterosis, the heterotic effect measured the difference between the average performance of the crossbreds and purebreds. The purebred genetic effect reflects the joint effect of additive and

maternal genetic effect differences between purebred Holsteins and purebred Jerseys. Differences for means and genetic effects were considered significant at $P < 0.05$ unless otherwise noted.

RESULTS AND DISCUSSION

BW

Purebred Holstein calves were 23.4 kg heavier on average than purebred Jersey calves from birth to 8 wk of age as a result of large purebred genetic effects (Table 3), an advantage also evidenced for Holstein birth weight in other designed crossbreeding experiments (Olson et al., 2009; Dhakal et al., 2013). The continued influence of Holstein genetics is reflected in comparisons using older purebred and crossbred calves (Hollon et al., 1972; Batra and Touchberry, 1974; Lee et al., 1988; Bjelland et al., 2011). Male calf BW increased more rapidly compared with female calves ($P < 0.05$), with an average BW gain of 33.3 kg compared with 31.0 kg for females by 8 wk of age (Table 4, Figure 1).

Overall colostrum lot differences did not affect BW; however, the interaction of colostrum lot and day was significant ($P < 0.01$). Calves fed lots 1 and 6 had an 11% greater BW gain at 56 d (lots 1 and 6 average $G56 = 30.9$ kg) compared with calves that received other colostrum lots (lots 2–5 average $G56 = 24.6$ kg). This may be indicative of a season effect rather than a differential colostrum effect. Calves born in the summer have shown lower DMI and ADG (Place et al., 1998). Consequently, BW may be negatively related to summer season. In this experiment, colostrum lots 1 and 6 were fed during the winter season, whereas the remaining lots were primarily fed during the summer season. The partial confounding of colostrum lot with season of birth may be responsible for differences in BW rather than colostrum lots. Other dependent variables had a significant ($P < 0.05$) colostrum lot-by-day interaction, likely representing a season effect rather than colostrum-quality effect.

DMI

Purebred and heterotic genetic effects influenced DMI of calves. Calves with Holstein genetics had greater DMI compared with purebred Jersey calves, and crossbred calves consumed 0.74 kg more DM than the average of the purebreds ($P < 0.05$; Table 3). An interaction for DMI between parity of dam and day reveals DMI was less than 5 kg for 21% of calves from multiparous dams compared with only 10% of calves from primiparous dams at 49 d of age (Figure 2). Fecal scores did not indicate any sickness among the calves during this

Table 3. Genetic-effect estimate results of growth and performance traits for Holstein × Holstein (HH), Holstein × Jersey (HJ), Jersey × Holstein (JH), and Jersey × Jersey (JJ) calves from birth to 8 wk of age

Genetic effect	Genetic-effect estimate						
	Repeated measure				Single measure		
	BW	DMI	Feed efficiency	Hip height	Gain to 42 d	Gain to 56 d	Days to weaning
Purebred (HH-JJ) ¹	23.45**	3.04**	−0.02	4.37*	5.48**	10.32**	−5.09
Heterotic ²	1.25	0.74*	−0.08	1.44*	−0.02	−0.72	−4.51†
Maternal (xH-xJ) ³	−2.03	−0.77	0.11	0.65	−1.03	−2.56†	3.92

¹Positive estimates indicate HH > JJ.²Positive estimates indicate crossbreds > purebreds.³Negative estimates indicate xJ > xH.** $P < 0.01$; * $P < 0.05$; † $P < 0.1$.

time period. Overall, calves born to multiparous dams consumed 6.2 kg of DMI, whereas calves of primiparous dams averaged 6.4 kg of DMI, indicating that although the rate of DMI differed over time for calves, by the end of the study, calves were consuming similar amounts of DM, regardless of the parity of the dam.

Hip Height

The skeletal measurement examined in this trial was calf hip height at birth and at 42 d of age, with

heavier birth weights positively associated with greater hip heights (Table 4). Similar to other growth traits, purebred genetic effects strongly influenced hip height (Table 3). Heterotic effects were significant ($P < 0.05$), and crossbred calves were 1.20 cm taller than the purebred calves. Into maturity, crossbred calves continue to exhibit similar structural measurements, including hip height, although this is not the case for every breed crossed with pure Holsteins (Hazel et al., 2014). Despite crossbred calves being taller and having greater

Table 4. *F*-values from mixed-model analyses of growth and performance parameters for Holstein × Holstein (HH), Holstein × Jersey (HJ), Jersey × Holstein (JH), and Jersey × Jersey (JJ) calves from birth to 8 wk of age

Source of variation	df	<i>F</i> -value						
		Repeated measure				Single measure		
		BW	DMI	Feed efficiency	Hip height	Gain to 42 d	Gain to 56 d	Days to weaning
Covariates ¹								
Dystocia	1	NA ²	NA	9.25**	NA	NA	NA	NA
Beginning BW	1	NA	NA	NA	13.37**	NA	NA	NA
Days to weaning	1	NA	NA	NA	NA	9.33**	6.85**	—
DMI	1	78.34**	—	NA	NA	36.02**	23.45**	NA
Genetic effects								
Purebred effects	1	70.13**	16.26**	0.00	5.74*	13.75**	20.17**	1.14
Heterotic effects	1	0.80	3.86*	0.20	5.37*	0.00	0.44	3.56†
Maternal effects	1	1.13	2.22	0.18	0.63	1.35	2.95	1.45
Fixed effect								
Sex	1	6.69*	2.16	0.00	0.04	3.53†	5.29*	0.70
Parity	1	3.62†	0.03	2.15	0.05	2.74	0.02	0.39
Colostrum lot	5	0.65	1.17	0.19	1.78	1.62	1.77	1.47
Day	8	223.70**	45.22**	1.22	287.44**	NA	NA	NA
Fixed effects interactions								
Sex by parity	1	NA	NA	NA	NA	5.86*	NA	NA
Sex by lot	5	NA	NA	NA	NA	NA	NA	NA
Sex by day	8	2.85**	NA	NA	NA	NA	NA	NA
Parity by day	8	NA	4.71**	NA	NA	NA	NA	NA
Parity by lot	6	NA	NA	NA	NA	NA	NA	NA
Lot by day	40	2.37**	3.54**	NA	2.35†	NA	NA	NA

¹Covariates were included only in applicable models. They were removed if $P > 0.10$.²Nonsignificant covariates ($P > 0.10$) and 2-way interactions ($P > 0.10$) were removed from final model to avoid overspecification. Variables that were not applicable to the model were not included; see Methods section for statistical models.** $P < 0.01$; * $P < 0.05$; † $P < 0.10$.

Figure 1. Body weight ($\pm$ SEM) difference of male (M) and female (F) calves from 7 to 56 d.

Figure 2. Dry matter intake ($\pm$ SEM) from 7 to 56 d of age for calves from primiparous (1) and multiparous (≥ 2) dams.

DMI relative to their purebred counterparts, these differences did not translate into improved feed efficiency.

Feed Efficiency

Genetic effects for FE were not significant (Table 3) in agreement with previous findings of no differences between purebred and crossbred cows (Ellersieck et al., 1977; Lee et al., 1988; Quigley and Wolfe, 2003; Heins et al., 2008). In contrast, Holstein male calves had a greater FE when compared with Jersey male calves from birth to 29 d of age (Jones et al., 2004), and additive effects on feed efficiency have been reported for postcalthood beef cattle (Ellersieck et al., 1977). Feed efficiency doubled at 7 wk of age for calves on this study, concurrent with a large increase in BW. This time period may be a point of inflection in the growth curve of the calves. It is possible that restricted milk feeding (at 10% of BW) obscured differences in feeding efficiencies. Khan et al. (2007) reported that calves fed greater volumes of milk had greater feed efficiencies than those on a restricted milk diet. Increased dystocia score was associated with increased FE ($P < 0.01$; Table 4) for unknown reasons.

BW Gain to 42 and 56 d

Dry matter intake and DWN strongly predicted G42 and G56 (Table 4). Furthermore, a strong purebred genetic effect ($P < 0.01$) favoring the Holstein breed was present for both G42 and G56 (Table 3). Calves with Holstein genetics gained 5.5 kg more than purebred Jersey calves at 42 d and 10.3 kg more at 56 d. Greater BW gain of older Holstein calves compared with purebred Jersey calves is well documented (Shreffler and Touchberry, 1959; Bereskin and Touchberry, 1967). In general, male calves tended to have greater gains

than female calves at 42 d ($P = 0.07$) and significantly greater G56 ($P < 0.05$). However, for G56, male calves born to multiparous dams did not have greater BW gain, though the reason for this is not clear (Figure 3). Higher ADG during the preweaning phase is also associated with greater milk yields during first lactation (Soberon et al., 2011).

Days to Weaning

Heterosis approached significance ($P = 0.06$) because crossbred calves tended to wean 4.5 d earlier than the average of the purebreds. Earlier weaning decreases feed and labor costs (Davis and Drackley, 1998; Kehoe et al., 2007) and age at first calving (Cady and Smith, 1996).

Figure 3. Body weight gain ($\pm$ SEM) at 42 d of age (Gain42) for male (M) and female (F) calves.

CONCLUSIONS

Purebred genetic effects significantly influenced all of the growth traits examined in this study with the exception of FE. Taken together with heterotic effects favoring increased DMI and hip height as well as a tendency to decrease DWN, calves with Holstein genetics, either purebred or crossbred, will exhibit strong performance through later calthood and maturity. Maternal effects, defined here as the percentage of Holstein genetics in the dam of the calf, did not appear to play a major role in the traits examined.

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