Three-breed rotational crossbreds of Montbéliarde, Viking Red, and Holstein compared with Holstein cows for dry matter intake, body traits, and production

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ABSTRACT

Rotational crossbred cows of the Montbéliarde, Viking Red, and Holstein (HO) breeds (CB) were compared with HO cows for dry matter intake (DMI), body weight (BW), cow height, body condition score (BCS), and production during the first 150 d of first, second, and third lactations. Primiparous and multiparous CB ($n = 63$ and 43 , respectively) and HO ($n = 60$ and 37 , respectively) cows calved from September 2014 to June 2017. Cows were fed the same total mixed ration twice daily, with refusals weighed once daily. The BW was recorded twice weekly, and height at the withers and the hips was recorded monthly. The BCS was evaluated weekly. The fat plus protein production from 4 to 150 d in milk was calculated from monthly test days using best prediction. Primiparous and multiparous cows were analyzed separately. Statistical analysis for primiparous cows included the fixed effects of year of calving and breed group, and the analysis for multiparous cows included the fixed effect of breed group and the repeated effect of cow nested within breed group. Primiparous CB cows (2,807 kg) had lower mean DMI than HO cows (2,948 kg) from 4 to 150 d in milk of first lactation. Mean BW was not different for the CB (562 kg) and HO (556 kg) cows, but primiparous CB cows had mean wither height that was 4.0 cm shorter and mean hip height that was 2.0 cm shorter than that of HO cows. Primiparous CB cows (3.46) had higher mean BCS compared with HO cows (3.20). Mean fat plus protein production did not differ for the primiparous CB and HO cows (331 vs. 329 kg, respectively). Multiparous CB cows (3,360 kg) also had lower mean DMI than HO cows (3,592 kg) and did not differ (636 kg) from HO cows (644 kg) for mean BW. The CB cows had mean wither height that was 3.5 cm shorter than that of HO cows, but mean hip height did not differ for multiparous CB (145.2 cm) and HO (146.4 cm) cows.

Mean BCS was higher for multiparous CB cows (3.25) than for HO cows (3.06), and mean fat plus protein production was not different for multiparous CB (445 kg) and HO (441 kg) cows. The lower DMI of the CB cows than HO cows resulted in less feed cost without loss of revenue from fat plus protein production.

Key words: crossbreeding, feed intake

INTRODUCTION

Change in milk pricing toward the solids in milk, reduction of fertility, health and survival of Holstein (HO) cows, and increase in average inbreeding of HO cows have each contributed to an increased number of crossbred dairy cows in the United States over the past 20 yr (Weigel and Barlass, 2003). Research on crossbreeding was conducted in the 1940s to learn whether dairy breeders could be as successful as corn breeders at creating productive hybrids (Fohrman et al., 1954). Numerous studies from the 1940s to 1990s had favorable results for crossbreds compared with purebreds (Touchberry, 1992); however, considerable pushback from breed associations as well as the higher average milk volume of HO cows resulted in the global domination by the HO breed beginning in the 1980s.

The HO breed has undergone extremely intense selection over the past 35 yr, and the selection emphasized production and conformation but ignored fertility and health until recently (VanRaden, 2017). The result was HO cows that were less fertile, more prone to health issues, and less likely to survive to later lactations than previously (Berry, 2018). In addition, selection over the past 35 yr favored larger and more angular cows, which resulted in cows that are not optimally functional for the commercial dairy industry (Hansen, 2000). Furthermore, acceleration of the annual increase of average inbreeding within the HO breed has increased the likelihood of expression of the deleterious effects from inbreeding depression, which are mainly related to fertility and fitness (Falconer and Mackay, 1996). The Council on Dairy Cattle Breeding (2018) reported that HO females born in 2018 had a mean inbreeding

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coefficient of 7.56% based on pedigree compared with 5.31% in 2007.

The benefits of crossbreeding for production, health, fertility, and survival of dairy cattle have been documented (López-Villalobos et al., 2000; Heins et al., 2012; Hazel et al., 2017a,b). Collecting data for feed intake (**FI**) of individual cows is costly because of the specialized labor and equipment that are required. Therefore, little research has been conducted on the FI of crossbred versus purebred cows. Typically, feed cost accounts for more than one-half of expenses for dairy cattle production (USDA ERS, 2018); therefore, efficient use of feed consumed by dairy cows is important for profitability. Body traits of cows such as BW, height, and BCS are also valuable for comparing crossbreds and purebreds for functionality and profitability in commercial dairies. Increased BCS is associated with improved fertility and health (Roche et al., 2009), and cows with extremely large or small frame size will not easily fit into modern freestalls and milking parlors.

Heins et al. (2008a) and Olson et al. (2010) compared Jersey $\times$ HO crossbred cows with HO for FI and body traits and reported the crossbreds consumed the same or less DMI or energy compared with HO cows but did not differ for fat or protein production. Heins et al. (2008b) found that Jersey $\times$ HO crossbred cows were shorter at the hips and had higher BCS than HO cows during first lactation. However, Heins et al. (2011) concluded that Jersey $\times$ HO crossbreds may not be well suited for high-production confinement systems because they were more likely to be culled for udder conformation and had lower mean fat and protein production in second and third lactations than HO cows.

For high-input confinement herds with limited opportunity for grazing, a 3-breed rotational system using the 3 breed groups of HO, Alpine, and Nordic Red has been recommended by Dechow and Hansen (2017). Specifically, interest is growing in an ongoing rotation including the HO, Montbéliarde (**MO**), and Viking Red (**VR**) breeds that is marketed internationally as ProCross by Coopex Montbéliarde (Roulans, France) and Viking Genetics (Randers, Denmark). The MO breed of dairy cattle in France has been selected over time for traits related to production, functionality, and conformation for efficient milk production (Montbéliarde Association, 2018a). Within conformation, the MO breed includes the trait of muscularity, which is subjectively measured at the withers and thighs and indirectly places a favorable weight on body condition (Montbéliarde Association, 2018a). The VR breed includes the subpopulations of Swedish Red, Finnish Ayrshire, and Danish Red, which have been combined for genetic improvement and marketing. Cows of the

VR breed tend to have lower milk volume, higher fat and protein solids in milk, and superior health and fertility than HO cows in Nordic countries (Jönsson, 2015) due to different selection goals over time (Oltenacu and Broom, 2010).

Hazel et al. (2013) reported that MO $\times$ HO crossbred cows were not different from HO cows for fat plus protein production during the first 150 d of first lactation. The MO $\times$ HO cows had 0.58 higher mean BCS and were 36 kg heavier for mean BW than HO cows, but they were not different for height at the hips than HO cows (Hazel et al., 2013). An Irish study comparing MO $\times$ HO and HO cows in a pasture production system found that DMI, BW, and fat plus protein production were not different for the 2 breed types (Buckley et al., 2007). The objective of this study was to compare 3-breed rotational crossbred cows of the MO, VR, and HO (referred to as **CB**) with HO cows for DMI, BW, cow height, BCS, and production during the first 150 d of their first 3 lactations.

MATERIALS AND METHODS

Experimental Design

Research with crossbreeding in the Dairy Cattle Teaching and Research Facility in St. Paul of the University of Minnesota began in the early 2000s. The initial crossbreds were Jersey $\times$ HO and MO $\times$ HO and, subsequently, 3-breed crossbreds of those breeds. The Jersey breed was later replaced with the VR breed for an ongoing 3-breed rotational system of HO, MO, and VR.

Sires of cows in this study were daughter-proven AI bulls, and 3 bulls were used as service sires annually from each of the 3 breeds. The HO bulls were chosen from among those ranking highly for the net merit index in the United States (VanRaden, 2017) with consideration of semen cost and were mated with both CB and HO cows. The MO and VR bulls were chosen from among those ranking highly for the French ISU index (Montbéliarde Association, 2018b) and the Nordic total merit index (Nordic Cattle Genetic Evaluation, 2018) that were available from Creative Genetics of California (Oakdale, CA), which is the United States importer. Matings of HO bulls with HO heifers and cows were assigned to minimize inbreeding coefficients. The CB heifers and cows were randomly mated to AI bulls from the appropriate breed (MO, VR, or HO) in rotation.

Cows in the study were born between 2012 and 2015, and their sires were selected between 2010 and 2013. The weighted mean birth year of the cows in the study was 2013 for both genetic groups. The weighted mean

birth year of all HO sires of cows was 2006, but the weighted mean birth year of the MO and VR sires of cows was 2002 and 2003, respectively. Therefore, the HO cows in this study had an advantage for genetic rank because the HO sires of cows tended to be younger than the MO and VR sires of cows.

Experimental Units

Cows were housed in the Dairy Cattle Teaching and Research Facility in St. Paul of the University of Minnesota. This experiment was approved by the Institutional Animal Care and Use Committee of the University of Minnesota (no. 1408-31736A). Cows calved seasonally between September and May. The CB and HO heifers were paired when possible before first calving according to age (mo) and expected calving date. All CB in this study were 3-breed crossbreds of MO, VR, and HO. First calving of cows was from September 2014 to April 2017. The cows that calved for the first time from September 2014 to May 2015 (yr 1) had the opportunity for 2 subsequent lactations to be included in the study. Cows that calved for the first time from September 2015 to April 2016 (yr 2) had the opportunity for 1 subsequent lactation to be included in the study. The cows that calved for the first time from August 2016 to April 2017 (yr 3) had the opportunity for only a first lactation to be included in the study. Some cows were involuntarily culled, and cows that left the herd before 150 DIM were eliminated from the study for only that terminal lactation. Less than 9% of the lactations of cows were eliminated for cows that left the herd before 150 DIM (Table 1). The resulting cows analyzed are summarized in Table 1. Of the 63 primiparous CB cows, 14 had an HO sire, 29 had an MO sire, and 20 had a VR sire. For multiparous CB cows, 43 lactations (15 with an HO sire, 15 with an MO sire, and 13 with a VR sire) were available for this study.

An attempt was made to collect FI for the 14 d prepartum; however, a large number of cows calved earlier than anticipated, and this resulted in a limited number of prepartum records for FI. Therefore, prepartum FI

is not reported in this study. Collection of FI and body trait observations of cows began 4 d postpartum and continued until 150 DIM. The objectives of this study did not include the investigation of lowly heritable traits such as fertility and survival because other studies with much larger sample sizes have compared CB and HO cows for those traits in commercial herds (Heins et al., 2012; Dezetter et al., 2015; Hazel et al., 2017a).

Collection of FI

Each cow was assigned to a tiestall in the barn for the duration of a lactation, and the stalls had mats augmented with wood shavings. The feed mangers in front of the cows were partitioned to provide each cow an exclusive feeding space. An identical TMR was delivered twice daily to cows in both genetic groups. The diets were formulated by a professional nutritionist to meet or exceed nutritional requirements (NRC, 2001). The amount fed to each cow aimed for at least a 5% daily refusal rate, and the amount fed was adjusted daily. Feed refusals were reclaimed and weighed daily before the first feed delivery. Amounts of feed delivered and reclaimed for individual cows was recorded electronically using Feed Supervisor software (Dresser, WI). Recording errors caused by computer malfunction or human error were removed, but they accounted for a small proportion (2.6%) of daily FI data. Missing daily FI were estimated by extrapolation using the mean from 2 d before and 2 d after the missing daily FI observation.

Samples of the TMR were collected twice weekly and stored in a freezer at -20°C . The 2 weekly samples were pooled into a single weekly sample and dried in an oven at 105°C for at least 16 h to determine DM content. Weekly samples were pooled into monthly samples and analyzed commercially (Rock River Laboratory, Watertown, WI) for nutrient analysis and energy calculations. Ingredient and nutrient composition of the TMR for the duration of the study is shown in Table 2. The daily DMI (kg) was calculated by multiplying daily FI by the DM content of the TMR. Daily DMI observa-

Table 1. Number of cow-lactations available for analysis by parity group and breed group

Item	Lactation 1		Lactation 2		Lactation 3	
	Holstein	3-breed crossbred ¹	Holstein	3-breed crossbred	Holstein	3-breed crossbred
Calved	63	70	31	38	9	11
Involuntarily culled before 150 DIM	3	7	3	4	0	2
Completed 150-d study	60	63	28	34	9	9

¹Three-breed (Montbéliarde, Viking Red, and Holstein) rotational crossbred cows.

tions were summed from 4 to 150 DIM to determine total DMI for each lactation.

Body Traits

The BW was recorded twice weekly with a digital scale when cows exited the milking parlor. Cow height was measured once monthly and consisted of height from the ground to the withers (**WH**) and height from the ground to the sacrum (hip height; **HH**). The WH and HH were recorded in increments of 0.5 cm. The BCS was evaluated on all cows once per week by a single trained evaluator and was scored on a 5-point scale with 0.25 increments, with 1 = thin and 5 = obese (Wildman et al., 1982). The means of BW, WH, HH, and BCS observations from 4 to 150 DIM were analyzed.

Production

Cows were milked twice daily at 0400 and 1600 h. Milk volume and fat and protein percentages from monthly DHI (Minnesota DHIA, Buffalo, MN) were used to estimate production for complete lactations with best prediction, which is used for national genetic evaluation in the United States (Cole and VanRaden, 2009). Each test day was required to have an observation for milk volume and fat and protein percentage,

and test day observations were excluded if milk was below 4.54 kg, fat percentage was outside the range of 1.0 to 9.0%, and protein percentage was outside the range of 1.0 to 6.0%; this affected a small number (<1%) of test days. The best prediction was adjusted for age at calving and previous days open. Daily estimates of milk volume (kg) and fat plus protein production (kg) from best prediction were summed from 4 to 150 DIM for each lactation.

Statistical Analysis

Lactational Analysis of DMI, BW, Cow Height, BCS, and Production. Exploratory data analysis revealed that primiparous cows decreased significantly ($P < 0.01$) by year for mean age at first calving as the study progressed (25.5 ± 2.4 , 24.2 ± 2.4 , and 22.9 ± 1.3 mo for yr 1, 2, and 3, respectively) because of changes in heifer rearing and herd management policies regarding age at calving. Also, preliminary analysis indicated that a covariable for age at calving (mo) did not consistently explain variation for the nonproduction traits beyond what was explained by year of calving. Consequently, primiparous and multiparous cows were analyzed separately because lactation curves differ substantially for traits such as DMI, BW, and production. Therefore, for primiparous cows, breed group (CB or HO) and year of calving (1, 2, or 3) were the fixed effects for statistical analysis of DMI, BW, WH, HH, BCS, milk volume (kg), and fat plus protein production (kg) from 4 to 150 DIM, and the GLM procedure of SAS (release 9.4, SAS Institute Inc., Cary, NC) was used to conduct the ANOVA and obtain solutions. For multiparous cows, the MIXED procedure of SAS was used to obtain solutions and conduct the ANOVA. Breed group (CB or HO) was a fixed effect, and cow nested within breed group was a repeated effect, with the variance components covariance structure used with the MIXED procedure because some cows had both second and third lactations. Cow nested within breed group was the error term to test the significance of breed group for the multiparous analysis.

Analysis of DMI, BW, BCS, and Production for 7-d Periods. A separate analysis was used to delineate differences of the CB and HO cows for intervals of time within the 4 to 150 DIM. Means for 21 periods of 7 d each (4–10 DIM, 11–17 DIM, and so on) within 4 to 150 DIM were analyzed for all traits except WH and HH. Analysis of mean DMI, BW, BCS, milk volume, and fat plus protein production for 7-d periods was done with the same models described previously but with 7-d period (1–21) and interaction of breed group and 7-d period added as fixed effects. Further-

Table 2. Mean TMR diet composition and nutrient density across the 3 yr of the study

Item	Value
Ingredient (% of DM)	
Alfalfa hay	7.7
Grass hay	1.0
Alfalfa haylage	8.3
Corn silage	30.0
Corn gluten feed	9.8
Corn grain, ground	13.1
Cottonseed, fuzzy	5.0
Molasses, liquid	3.2
Protein, mineral, and vitamin mix ¹	20.8
Energy Booster 100 ²	1.1
Nutrient composition	
DM (%)	54.6
CP (% of DM)	16.6
ADF (% of DM)	19.7
NDF (% of DM)	30.2
NE _L (Mcal/kg of DM)	1.62

¹Protein mix included fine rolled corn (29.7%), soybean meal (17.5%), canola meal (12.5%), AminoPlus (8.75%; Ag Processing Inc., Omaha, NE), blood meal (6.25%), calcium (5.5%), dry distillers grain (5.0%), sodium bicarbonate (5.0%), microminerals (2.5%), Ultramet (2.0%; Vita Plus Corp., Madison, WI), potassium carbonate (2.0%), white salt (2.0%), urea (1.25%), and Rumensin (0.03%; Elanco Animal Health, Greenfield, IN) on a DM basis.

²Hydrogenated fat (Milk Specialties, Eden Prairie, MN).

more, a statistical contrast of breed groups for each 7-d period was conducted. Primiparous and multiparous cows were again analyzed separately, and the MIXED procedure of SAS was used to conduct the ANOVA and obtain solutions for traits during the 7-d periods for both primiparous and multiparous cows. The first-order autoregressive covariance structure was used for 7-d period in the MIXED procedure because it resulted in the lowest Akaike information criterion (Littell et al., 2006).

Data were from a single herd, so the number of CB cows sired by bulls from each of the 3 breeds was not large. Therefore, breed of sire of CB cows was not included in the statistical analysis. The goal of this study was to compare a mixture of generations and sire breeds representing the 3-breed rotational (CB) system with the HO cows and was not to compare breeds of sire within CB.

RESULTS

Effect of Year of Calving for Primiparous Cows

Year of calving significantly ($P < 0.01$) explained variation of lactational DMI, BCS, milk volume, and fat plus protein production for primiparous cows. The cows that calved for the first time in yr 1 had the oldest mean age at calving (Table 3) but had less milk volume and less fat plus protein production ($P < 0.01$) than the cows that calved for the first time in yr 2 and 3, and these differences likely resulted from their lower mean BW (Table 3). Primiparous cows that calved in yr 3 had higher DMI ($P < 0.01$) and had higher BCS ($P < 0.05$) than cows that calved in yr 1 and 2 (Table 3). The effect of year of calving was not significant ($P = 0.50$) for explaining variation of WH for primiparous cows; however, primiparous cows that calved in yr 2 had taller ($P < 0.05$) HH than cows that calved in yr 1 (Table 3). Both the CB and HO heifers that calved in

yr 1 were grown on pasture when available with little energy supplementation. On the other hand, the heifers that calved in yr 2 and 3 were raised at a different location and were provided energy supplementation in addition to seasonal pasture access before first calving.

Lactational DMI, BW, Cow Height, BCS, and Production

Primiparous and multiparous CB cows consumed 141 kg less ($P < 0.01$) and 232 kg less ($P = 0.02$) mean DMI, respectively, than HO cows from 4 to 150 DIM, but mean BW did not differ ($P > 0.53$) for the 2 breed groups within parity group (Table 4). Primiparous CB cows were 4.0 cm shorter ($P < 0.01$) for mean WH than HO cows, and multiparous CB cows were 3.5 cm shorter ($P < 0.01$) for mean WH than HO cows. Mean HH was 2.0 cm shorter ($P < 0.01$) for primiparous CB cows than for HO cows, but mean HH did not differ ($P = 0.16$) for multiparous CB and HO cows (Table 4). Primiparous and multiparous CB cows had higher ($P < 0.01$) mean BCS (+0.26 and +0.19, respectively) than HO cows (Table 4). Primiparous and multiparous CB cows produced 206 and 372 kg less ($P < 0.02$) mean milk volume, respectively, from 4 to 150 DIM than the HO cows, but the CB cows were not different ($P > 0.68$) from the HO cows for fat plus protein production (Table 4).

DMI, BW, BCS, and Production for 7-d Periods

DMI. Year of calving, breed group, and 7-d period all significantly ($P < 0.01$) explained variation of DMI for primiparous cows. The interaction of breed group and 7-d period was not significant ($P = 0.38$). However, statistical contrasts of breed groups for individual 7-d periods indicated that primiparous CB cows had less ($P < 0.05$) mean DMI than the HO cows for most of the 7-d periods beginning in period 6 (Figure 1). Both the

Table 3. Least squares means and SEM for the effect of year (1, 2, or 3)¹ for DMI, BCS, BW, wither height (WH), hip height (HH), milk volume, and fat plus protein production from 4 to 150 DIM for primiparous cows

Trait	Year 1 (n = 48)		Year 2 (n = 37)		Year 3 (n = 38)	
	LSM	SE	LSM	SE	LSM	SE
DMI (kg)	2,823 ^a	41.3	2,744 ^a	47.0	3,067 ^b	46.4
BW (kg)	544 ^a	7.9	562 ^{ab}	9.0	570 ^b	8.9
WH (cm)	137.0	0.6	138.0	0.7	137.1	0.7
HH (cm)	142.6 ^a	0.6	144.3 ^b	0.6	143.0 ^{ab}	0.6
BCS	3.25 ^a	0.03	3.31 ^a	0.04	3.43 ^b	0.04
Milk (kg)	4,508 ^a	53.8	4,731 ^b	61.2	4,762 ^b	60.4
Fat + protein (kg)	317 ^a	3.7	338 ^b	4.2	335 ^b	4.1

^{a,b}LSM across columns with different superscripts are significantly different ($P < 0.05$).

¹Mean age at calving of 25.5 ± 2.4 mo (yr 1), 24.2 ± 2.4 mo (yr 2), and 22.9 ± 1.3 mo (yr 3).

CB and HO cows increased in DMI from 4 to 150 DIM, and the statistical contrasts between primiparous CB and HO cows for DMI became more significant with time.

For multiparous cows, both breed group and 7-d period significantly ($P < 0.01$) explained variation of DMI, but the interaction of breed group and 7-d period did not ($P = 0.98$). From the statistical contrasts, multiparous CB cows consumed less mean DMI ($P < 0.05$) during most 7-d periods than multiparous HO cows beginning with period 6 (Figure 1). However, the largest difference in DMI for breed groups occurred in periods 10 to 14 based on the strength of the statistical contrasts for breed groups. Contrary to the DMI lactation curve for primiparous cows, the difference in DMI for CB and HO cows became less pronounced in periods 15 to 21. For both the primiparous and multiparous cows, breed groups rapidly increased in DMI during early lactation because cows required increased DMI to cope with the energy demands for production.

BW. Year of calving and 7-d period significantly ($P < 0.05$) explained variation for primiparous cows. However, breed group ($P = 0.58$) and the interaction of breed and 7-d period ($P = 0.83$) were not significant, and none of the statistical contrasts between breed groups for the 7-d periods differed for BW. Primiparous CB and HO cows both reached their lowest BW in period 3,

Figure 1. Least squares means of DMI (kg) for 7-d periods for the primiparous and multiparous Holstein and 3-breed (Montbéliarde, Viking Red, and Holstein) rotational crossbred cows. Error bars represent SEM of DMI, and symbols above the LSM represent the significance of breed group differences for 7-d periods from statistical contrasts († $P < 0.10$, * $P < 0.05$, and ** $P < 0.01$). The 7-d periods correspond to DIM: 1 (4–10), 2 (11–17), 3 (18–24), 4 (25–31), 5 (32–38), 6 (39–45), 7 (46–52), 8 (53–59), 9 (60–66), 10 (67–73), 11 (74–80), 12 (81–87), 13 (88–94), 14 (95–101), 15 (102–108), 16 (109–115), 17 (116–122), 18 (123–129), 19 (130–136), 20 (137–143), and 21 (144–150).

Table 4. Least squares means and SEM for DMI, BCS, BW, wither height (WH), hip height (HH), milk volume, and fat plus protein production from 4 to 150 DIM by parity and breed group

Item	Holstein		3-breed crossbred ¹	
	LSM	SE	LSM	SE
Primiparous				
Cows (no.)	60		63	
DMI (kg)	2,948	36.9	2,807**	36.3
BW (kg)	556	7.1	562	7.0
WH (cm)	139.4	0.5	135.4**	0.5
HH (cm)	144.3	0.5	142.3**	0.5
BCS	3.20	0.03	3.46**	0.03
Milk (kg)	4,770	48.1	4,564**	47.2
Fat + protein (kg)	329	3.3	331	3.2
Multiparous				
Cows (no.)	37		43	
DMI (kg)	3,592	68.1	3,360*	63.1
BW (kg)	644	10.2	636	9.4
WH (cm)	143.7	0.7	140.2**	0.6
HH (cm)	146.4	0.7	145.2	0.6
BCS	3.06	0.04	3.25**	0.04
Milk (kg)	6,636	111.2	6,264*	103.1
Fat + protein (kg)	441	7.0	445	6.5

¹Three-breed (Montbéliarde, Viking Red, and Holstein) rotational crossbred cows.

* $P < 0.05$, ** $P < 0.01$ for differences from Holstein within parity group.

and cows in both breed groups increased ($P < 0.05$) in mean BW in periods 3 to 21. The least squares means indicated that cows in both breed groups lost BW at the beginning of lactation ($P < 0.01$ from a statistical contrast of period 1 and period 3), as expected, because cows mobilize body tissue to gain energy for production (Figure 2). Both CB and HO cows had greater ($P < 0.01$) mean BW in the last 7-d period than in the first 7-d period, and this reflected continued growth toward mature BW.

For multiparous cows, only 7-d period ($P < 0.01$) among the effects in the model approached statistical significance ($P < 0.10$) for explaining variation of BW. Like for primiparous cows, the 7-d periods for multiparous CB and HO did not differ for mean BW (Figure 2), and both CB and HO cows lost BW at the begin-

ning of lactation ($P < 0.01$). Multiparous CB and HO cows reached their lowest mean BW in periods 3 to 6.

BCS. Year of calving, breed group, and 7-d period significantly ($P < 0.01$) explained variation of BCS for primiparous cows; however, the interaction of breed group and 7-d period was not significant ($P = 0.78$). Primiparous CB cows had higher ($P < 0.01$) mean BCS in every 7-d period than the HO cows (Figure 3). Both CB and HO primiparous cows lost BCS ($P < 0.01$) at the beginning of lactation. The CB cows had BCS of 3.41 to 3.48 in periods 3 to 21, with their lowest mean BCS in period 10. The primiparous HO cows reached the lowest mean BCS in period 6, but they were relatively constant ($P > 0.05$) for BCS in periods 5 to 21, with a mean BCS of 3.14 to 3.24 in those periods.

Breed group and 7-d period significantly ($P < 0.01$) explained variation of BCS, and the interaction of

Figure 2. Least squares means of BW (kg) for 7-d periods for the primiparous and multiparous Holstein and 3-breed (Montbéliarde, Viking Red, and Holstein) rotational crossbred cows. Error bars represent SEM of BW, and breed groups did not differ for BW. The 7-d periods correspond to DIM: 1 (4–10), 2 (11–17), 3 (18–24), 4 (25–31), 5 (32–38), 6 (39–45), 7 (46–52), 8 (53–59), 9 (60–66), 10 (67–73), 11 (74–80), 12 (81–87), 13 (88–94), 14 (95–101), 15 (102–108), 16 (109–115), 17 (116–122), 18 (123–129), 19 (130–136), 20 (137–143), and 21 (144–150).

Figure 3. Least squares means of BCS for 7-d periods for the primiparous and multiparous Holstein and 3-breed (Montbéliarde, Viking Red, and Holstein) rotational crossbred cows. Error bars represent SEM of BCS, and symbols above the LSM represent the significance of breed group differences for 7-d periods from statistical contrasts ($\dagger P < 0.10$, $*P < 0.05$, and $**P < 0.01$). The 7-d periods correspond to DIM: 1 (4–10), 2 (11–17), 3 (18–24), 4 (25–31), 5 (32–38), 6 (39–45), 7 (46–52), 8 (53–59), 9 (60–66), 10 (67–73), 11 (74–80), 12 (81–87), 13 (88–94), 14 (95–101), 15 (102–108), 16 (109–115), 17 (116–122), 18 (123–129), 19 (130–136), 20 (137–143), and 21 (144–150).

breed group and 7-d period tended ($P = 0.10$) to explain variation for multiparous cows. Multiparous CB cows had higher mean BCS ($P < 0.05$) than HO cows in every 7-d period except period 5, when the CB cows tended ($P = 0.10$) to have higher BCS than HO cows (Figure 3). Like the primiparous cows, multiparous CB and HO cows both lost BCS at the beginning of lactation (Figure 3). In periods 7 to 21, multiparous CB cows had BCS of 3.17 to 3.25 and multiparous HO cows had BCS of 2.97 to 3.07.

Production. For primiparous cows, year of calving, breed group, and 7-d period all significantly ($P < 0.01$) explained variation of milk volume. The interaction of breed group and 7-d period tended ($P = 0.08$) to explain variation in milk volume. Primiparous CB cows produced less milk volume ($P < 0.05$) than HO cows in every 7-d period (Figure 4). The highest mean milk

Figure 4. Least squares means of milk volume (kg) for 7-d periods for the primiparous and multiparous Holstein and 3-breed (Montbéliarde, Viking Red, and Holstein) rotational crossbred cows. Error bars represent SEM of milk volume, and symbols above the LSM represent the significance of breed group differences for 7-d periods from statistical contrasts ($\dagger P < 0.10$, $*P < 0.05$, and $**P < 0.01$). The 7-d periods correspond to DIM: 1 (4–10), 2 (11–17), 3 (18–24), 4 (25–31), 5 (32–38), 6 (39–45), 7 (46–52), 8 (53–59), 9 (60–66), 10 (67–73), 11 (74–80), 12 (81–87), 13 (88–94), 14 (95–101), 15 (102–108), 16 (109–115), 17 (116–122), 18 (123–129), 19 (130–136), 20 (137–143), and 21 (144–150).

volume of CB cows was near 33.0 kg/d in periods 12 to 15, whereas the highest mean milk volume in HO cows was 34.4 to 35.5 kg/d in periods 12 to 14.

For multiparous cows, breed group, 7-d period, and their interaction all significantly ($P < 0.05$) explained variation of milk volume. The CB and HO cows did not differ ($P > 0.06$) in mean milk volume until period 8, when HO cows began to have higher ($P < 0.05$) milk volume than CB cows through 150 DIM (Figure 4). Multiparous CB cows had their highest milk volume of 45.2 to 45.3 kg/d in periods 7 to 9, and multiparous HO cows had their highest milk volume of 47.7 to 47.8 kg/d in periods 9 to 11. Multiparous cows reached peak milk volume earlier within lactation than they reached peak DMI. Multiparous cows of both breed groups also

Figure 5. Least squares means of fat plus protein production (kg) for 7-d periods for the primiparous and multiparous Holstein and 3-breed (Montbéliarde, Viking Red, and Holstein) rotational crossbred cows. Error bars represent SEM of fat plus protein production, and breed groups did not differ for fat plus protein production. The 7-d periods correspond to DIM: 1 (4–10), 2 (11–17), 3 (18–24), 4 (25–31), 5 (32–38), 6 (39–45), 7 (46–52), 8 (53–59), 9 (60–66), 10 (67–73), 11 (74–80), 12 (81–87), 13 (88–94), 14 (95–101), 15 (102–108), 16 (109–115), 17 (116–122), 18 (123–129), 19 (130–136), 20 (137–143), and 21 (144–150).

reached highest milk volume sooner within lactation than primiparous cows.

For primiparous cows, year of calving and 7-d period significantly ($P < 0.01$) explained variation for fat plus protein production, whereas breed group ($P = 0.75$) and the interaction of breed group and 7-d period ($P = 0.54$) did not. However, the CB cows did not differ from HO cows for mean fat plus protein production for any of the 7-d periods. In comparison with milk volume, primiparous cows increased in fat plus protein production at the beginning of lactation and then plateaued until 150 DIM (Figure 5). Primiparous CB cows plateaued at 2.34 to 2.35 kg of fat plus protein production/d in periods 14 to 21, and primiparous HO cows plateaued at 2.32 to 2.33 kg of fat plus protein production/d in periods 13 to 21.

For multiparous cows, only 7-d period ($P < 0.01$) among the effects in the model approached statistical significance ($P < 0.10$) for explaining variation of fat plus protein production. Like the primiparous cows, multiparous CB cows did not differ from HO cows for fat plus protein production for any of the 7-d periods (Figure 5). Multiparous CB cows increased in fat plus protein production at the beginning of lactation, plateaued in periods 5 to 9 at 3.11 to 3.13 kg of fat plus protein/d, and then decreased for fat plus protein production through 150 DIM. Multiparous HO cows were similar to CB cows but plateaued at 3.08 to 3.10 kg of fat plus protein/d in periods 5 to 10.

DISCUSSION

Differences in DMI between CB and HO cows may reflect differences of the pure breeds of HO, MO, and VR for DMI of cows. Ntallaris et al. (2017) compared pure VR cows with pure HO cows for DMI, production, and energy balance in a Swedish confinement herd and reported that primiparous VR cows consumed 9.3% less DMI, produced 14% less ECM, had more BCS, and mobilized less body condition than HO cows from calving to 120 DIM, although sample sizes were small. Furthermore, Ntallaris et al. (2017) suggested that the HO cows in their study prioritized production over fertility and health more than did the VR cows and that the HO cows required more DMI than the VR cows, possibly because the HO cows had higher production and lower baseline BCS at calving.

Buckley et al. (2007) and Walsh et al. (2008) compared pure HO, pure MO, and MO $\times$ HO crossbred cows in a grazing system, and they reported that pure MO cows had 5.7% lower DMI, 13% lower milk volume, 15.6% lower fat plus protein production (kg), and 0.38 higher BCS than HO cows. Also, both studies found that MO $\times$ HO cows were not different from HO cows for DMI, milk volume, or fat plus protein production but that MO $\times$ HO cows had 0.23 higher BCS than HO cows (Buckley et al., 2007; Walsh et al., 2008). In our study, both primiparous and multiparous CB and HO cows did not differ for fat plus protein production; however, CB cows had lower DMI and lower milk volume but higher BCS than HO cows. Differences in milk volume and BCS, despite no difference for fat plus protein production, may have accounted for some of the difference in DMI of the breed groups in this study. The HO cows in this study may have required more DMI to produce more fluid carrier (water) and lactose in their milk compared with the CB cows. Heterosis of crossbreds for DMI could potentially explain some of the difference in DMI from HO cows in addition to breed differences for additive genetic effects. However,

heterosis could not be estimated in this study because pure MO and VR cows were not available for comparison.

Composition of refusals was not analyzed in this study, and breed groups potentially could have sorted TMR differently, which also could have had a small influence on differences in DMI. Furthermore, the higher DMI of the HO cows could have led to a small reduction of digestibility of the diet because of a higher rate of passage through the digestive system (Colucci et al., 1982). Differences in the microbiome of cows in this study may also have played a role in breed group differences for DMI. Gonzalez-Recio et al. (2018) reported differences in the microbiome of HO and Brown Swiss cows fed the same diets, and they suggested that genetics of cows may explain differences of the microbiome they harbor. The MO and VR breeds have been genetically improved in northern Europe based on diets with emphasis on rye grass. On the other hand, the HO breed has been genetically improved in North America based on TMR diets, like those used in this study, with emphasis on legumes and corn silage.

The CB and HO cows in this study did not differ for BW, and this was likely because the CB cows had smaller mean WH but higher mean BCS than the HO cows. The differences in WH and BCS were anticipated because of different selection goals for the HO, MO, and VR breeds. For the HO breed, a positive genetic trend for body size composite, which placed 50% emphasis on stature until 2016 (Holstein Association USA Inc., 2016), has resulted in HO cows that are taller in the front (WH) despite a negative weight on body size composite in the net merit index (VanRaden et al., 2014; VanRaden, 2017). Furthermore, the HO breed has strongly selected for lower BCS and continues to do so with the negative weight on BW composite in the net merit index (Holstein Association USA Inc., 2017; VanRaden, 2017). The MO breed has historically selected for cows to maintain BCS and has selected for fertility and survival for 20 yr (Barbat et al., 2010). The VR breed has ignored both stature and BCS for selection but has selected for fertility for more than 30 yr in their selection indices (Pryce et al., 2014). Increased BCS has a favorable relationship with fertility and health (Roche et al., 2009).

In commercial herds in the United States, primiparous MO $\times$ HO and VR $\times$ HO crossbred cows were shorter for mean WH and had 0.38 higher BCS than HO cows (Hazel et al., 2017a), and these results are similar to those in this study for primiparous CB and HO cows. However, the cows in Hazel et al. (2017a) were only scored once for BCS in early lactation, and BW was not available. Like this study of CB and HO cows, Walsh et al. (2008) found no differences in BW

for mixed-parity MO $\times$ HO crossbred cows compared with HO cows, and their cows reached nadir BW between 5 and 8 wk of lactation. In contrast, Hazel et al. (2013) reported that primiparous MO $\times$ HO cows had 36 kg higher BW compared with primiparous HO cows, but this was likely because MO $\times$ HO cows had much higher BCS (+0.58) and similar HH in the first 150 DIM compared with HO cows. Both Hazel et al. (2013) and Walsh et al. (2008) found that both MO $\times$ HO and HO cows lost body condition in early lactation but, similar to CB cows in this study, the MO $\times$ HO crossbred cows maintained higher BCS during the first half of lactation.

The DMI and BCS of growing heifers were not evaluated. Also, DMI and BCS were not available for cows after 150 DIM or during the dry period; therefore, the DMI and BCS of CB and HO cattle during those periods of time are unknown. However, results from this study suggest that both primiparous and multiparous CB cows maintained a higher baseline BCS compared with HO cows over time, with essentially a uniform difference between CB and HO cows from 4 to 150 DIM. This was supported by Hazel et al. (2014), who observed that BCS from calving to 300 DIM and across the first 5 lactations was higher for MO-sired crossbred cows than HO cows.

The CB cows in this study had lower milk volume than HO cows, but the CB and HO cows were not different for fat plus protein production (kg). Fluid milk volume is too frequently used as the sole measure of productivity of cows on dairy farms; however, most dairy producers in the United States are paid primarily for the fat and protein solids in milk rather than the fluid carrier of milk. The HO breed has a documented advantage over other breeds for fluid milk volume. However, pure MO (Dezetter et al., 2015) and pure VR (Jönsson, 2015) cows have higher fat and protein percentages in their milk than HO cows. The MO and VR breeds have not historically placed selection emphasis on milk volume; rather, both breeds have selected for fat and protein production (kg), for fertility, and for cow health or survival (Oltenuacu and Broom, 2010).

Other studies, like this study, have reported lower milk volume (−2.1 to −6.1%) for 2-breed and 3-breed crosses of the HO, MO, and VR breeds (Heins et al., 2006; Malchiodi et al., 2011; Hazel et al., 2017b). Heins et al. (2006) found that primiparous MO $\times$ HO cows had 3.8% less fat plus protein production (kg) than HO cows, whereas Nordic Red $\times$ HO cows had no differences for fat plus protein production from HO cows. Malchiodi et al. (2011) reported that CB cows from a single herd in northern Italy had 5.5% less fat production and no difference for protein production than

HO cows during their first 2 lactations. More recently, Hazel et al. (2017b) reported that MO $\times$ HO and VR $\times$ HO primiparous crossbreds collectively had 1.9% more fat plus protein production than their HO herdmates. Conflicting results for fat plus protein production for cows in the various studies could have resulted from genetic level of sires of cows within breeds or from differences in herd management.

Because the CB cows were not different for fat plus production but had significantly lower DMI than HO cows, the CB cows in this study were superior to the HO cows for income over feed cost. With feed cost estimated at \$0.2936/kg of DM (Center for Farm Financial Management, 2017) and production valued at \$5.3741/kg of fat and \$4.8674/kg of protein (USDA AMS, 2018), the income over feed cost was \$50 higher for primiparous and \$88 higher for multiparous CB cows than HO cows from 4 to 150 DIM.

CONCLUSIONS

During the past decade, interest in crossbreeding has grown for dairy cattle because the deficiencies of pure HO cows for fertility, health, and survival have become more pronounced. Because most crossbred cows have higher BCS and lower milk volume than HO cows, some may have assumed that crossbred dairy cows must have lower fat plus protein production than HO cows. However, the CB cows in this study did not differ from HO cows for fat plus protein production (kg) from 4 to 150 DIM in their first 3 lactations. Also, CB cows consumed less DMI than HO cows, did not differ for BW from HO cows, were shorter for WH than HO cows, and had higher BCS than HO cows. Therefore, the lower DMI of CB than HO cows resulted in less feed cost without loss of revenue from fat plus protein production. Furthermore, higher BCS is documented to have a positive relationship with improved fertility and reduced health disorders of cows. The comparison of CB and HO cows in this study suggests that CB cows may have advantages for profitability over HO cows for commercial milk production.

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