Comparison of 3-breed rotational crossbreds of Montbéliarde, Viking Red, and Holstein with Holstein cows fed 2 alternative diets for dry matter intake, production, and residual feed intake

G. M. Pereira,1,2 B. J. Heins,1* B. Visser,3 and L. B. Hansen2
1Department of Animal Science, University of Minnesota, St. Paul 55108
2West Central Research and Outreach Center, University of Minnesota, Morris 56267
3Vita Plus, Madison, WI 53713

ABSTRACT

The objective of this study was to compare 3-breed rotational crossbred (CB) cows of the Montbéliarde, Viking Red, and Holstein (HO) breeds with HO cows fed 2 alternative diets for dry matter intake (DMI), fat plus protein production (CFP), body weight (BW), body condition score (BCS), feed efficiency, and residual feed intake (RFI) from 46 to 150 days in milk (DIM) during first lactation. The CB cows (n = 17) and HO cows (n = 19) calved from September 2019 to March 2020. Cows were fed either a traditional total mixed ration diet (TRAD) or a higher fiber, lower starch total mixed ration diet (HFLS). The HFLS had 21% more corn silage, 47% more alfalfa hay, 44% less corn grain, and 43% less corn gluten feed than the TRAD. The 2 diets were analyzed for dry matter content, crude protein, forage digestibility, starch, and net energy for lactation. The BW and BCS were recorded once weekly. Daily milk, fat, and protein production were estimated from twice monthly milk recording with random regression. Measures of efficiency were CFP per kilogram of DMI and DMI per kilogram of BW. The RFI from 46 to 150 DIM was the residual error from regression of DMI on milk energy, metabolic BW, and the energy required for change in BW. Statistical analysis of all variables included the fixed effects of diet, breed group, and the interaction of diet and breed group. The CB cows fed HFLS had less DMI (−12%) and lower DMI/BW (−14%) compared with the HO cows fed TRAD. For CFP, CB and HO cows were not different when fed TRAD or HFLS. Furthermore, the CB cows fed HFLS had higher BW (+50 kg) compared with HO cows fed HFLS. The CB cows fed TRAD had higher BCS than HO cows fed TRAD and HO cows fed HFLS (+0.46 and +0.62, respectively). The HO cows fed TRAD had more DMI (+14%) and lower CFP per kilogram of DMI (−12%) compared with the HO cows fed HFLS. In addition, mean RFI from 46 to 150 DIM was lower and more desirable for CB cows fed HFLS (−120.0 kg) compared with HO cows fed TRAD (85.3 kg). Dairy producers may feed either TRAD or HFLS to CB cows without loss of CFP.

Key words: crossbreeding, residual feed intake, Montbéliarde

INTRODUCTION

Feed costs affect the profitability of dairy farms and represent 47% of the total costs of US milk production (USDA-ERS, 2021b). In recent years, corn prices have increased because of the demand for ethanol (USDA-ERS, 2021a), and dairy producers have experienced volatility of cost when purchasing grain for dairy cow diets. Therefore, dairy producers have explored alternative diets for dairy cattle that contain more forage and less concentrate to improve profitability.

Research of crossbred (CB) cows has predominantly focused on production, fertility, and health, but little research has compared CB cows and Holstein (HO) cows for feed efficiency. The DMI and feed efficiency of CB and HO cows fed the same TMR have been compared in confinement herds (Heins et al., 2008; Olson et al., 2010; Hazel et al., 2013; Shonka-Martin et al., 2019a, b). Heins et al. (2008) reported CB cows of Jersey (JE) × HO did not differ for DMI and fat plus protein production (CFP) compared with HO cows; however, the CB cows had less BW and higher BCS than HO cows during the first 150 d of first lactation. Furthermore, Olson et al. (2010) found HO × JE cows did not differ for DMI and fat plus protein production (CFP) compared with HO cows; however, the CB cows had less BW and higher BCS than HO cows during the first 150 d of first lactation. Three-breed CB cows of MO, Viking Red (VR), and HO breeds had lower DMI, similar BW, and had higher

Received January 5, 2022.
Accepted June 6, 2022.
*Corresponding author: hein0106@umn.edu
BCS compared with HO cows from 4 to 150 DIM during first lactation (Shonka-Martin et al., 2019a,b).

Feed intake of CB and HO cows that were fed higher forage and lower starch diets has been compared in low-input and pasture-based herds (Xue et al., 2011; Ferris et al., 2018). Xue et al. (2011) compared JE × HO and HO cows fed a diet of grass silage and either 30 or 70% concentrate and reported DMI, milk production, and energy efficiency did not differ across first lactation. However, across the 2 diets the CB cows had similar BW and higher BCS compared with HO cows (Xue et al., 2011). Swedish Red × (JE × HO) cows and HO cows did not differ for DMI and milk production fed low versus medium concentrate diets in a pasture-based herd. Furthermore, the CB cows had higher BCS compared with HO cows for the 2 diets (Ferris et al., 2018).

Recently, the Feed Saved trait has been incorporated into the US Lifetime Net Merit Index for the HO breed with a goal of improving feed efficiency and profitability of dairy cattle (VanRaden et al., 2021) and is the expected pounds of feed not consumed per lactation. Feed Saved is a combination of PTA for BW composite and residual feed intake (RFI). The RFI is the difference between actual DMI and expected DMI, and a cow with a negative or lower RFI is more favorable. The expected DMI for a cow can be derived from requirements for maintenance, BW change, and milk production (VandeHaar et al., 2016). The most common energy sinks reported for dairy cattle are production, metabolic BW, and the energy required for BW change (Hardie et al., 2015; Shonka-Martin et al., 2019b).

Shonka-Martin et al. (2019b) reported 3-breed CB cows of MO, VR, and HO breeds had a lower mean RFI compared with HO cows fed a similar TMR during the first 150 d of first lactation. Dairy producers have hypothesized 3-breed rotational CB cows of MO, VR, and HO are more feed efficient than HO cows fed a TMR with more fiber and less starch. Currently, a TMR based on corn silage is fed to most cows in confinement herds in the United States, and dairy producers have explored alternative diets to improve nutrient digestibility, feed efficiency, and profitability of cows. Therefore, the objective of this study was to assess the effects of feeding 2 alternative diets to 3-breed rotational CB cows of MO, VR, and HO versus HO cows for DMI, CFP, BW, BCS, feed efficiency, and RFI from 46 to 150 DIM during first lactation.

**MATERIALS AND METHODS**

**Experimental Design and Data**

The University of Minnesota initiated research on crossbreeding of dairy cattle in 2000, and 50% of HO heifers and cows were mated to JE AI bulls and the other 50% were mated to HO AI bulls at that time. Subsequently, all JE × HO heifers and cows were mated to MO AI bulls to initiate a 3-breed rotational CB system. In 2009, the JE breed was replaced with the VR breed to continue a 3-breed rotational CB system. A description of the crossbreeding design and bull selection for breeds was reviewed in Shonka-Martin et al. (2019a), and CB cows were 3-breed rotational CB of MO, VR, and HO.

Cows were housed at the Dairy Cattle Teaching and Research Facility of the University of Minnesota in St. Paul. All animal care and management practices were approved by the Institutional Animal Care and Use Committee at the University of Minnesota (#1907-37226A). Primiparous cows calved from September 2019 to March 2020. In total, 42 cows (21 CB, 21 HO) calved for the study. However, 3 cows (2 CB, 1 HO) were involuntarily culled from the herd before 150 DIM and, therefore, were removed from the study. Also, 3 cows were removed because of unusually low CFP (<200 kg) for the 105 d. One CB and 1 HO cow fed HFLS, and 1 CB cow fed TRAD, were removed for low CFP and the cows were removed because they were greater than 2.5 standard deviations from the mean of each breed group and diet. The 36 cows (17 CB, 19 HO) that remained were unimpaired experimental units with data available from 46 to 150 DIM.

**Collection of Feed Intake and Diets**

Cows were assigned to an individual tiestall in a confinement barn for the duration of the study, and the feed mangers were partitioned to provide each cow an exclusive feeding space. Drinking cups provided water ad libitum for cows. Feed was delivered once daily and allowed for a feed refusal rate of approximately 5%. Refusal rate was the actual feed intake refused by cows divided by the actual feed intake offered to cows. Individual feed refusals were reclaimed and weighed daily before new feed was delivered. The feed delivered and the refusals were electronically recorded with Feed Supervisor (Supervisor Systems) software. Data with errors because of human and computer malfunction were removed and accounted for 1.3% of data for daily feed intake. Missing observations were estimated from the mean of 1 d before and 1 d after the missing observation of daily feed intake. However, if 2 consecutive days had missing observations, the daily feed intake was estimated from the mean of 2 d before and 2 d after the missing observations.

Diets fed to cows were formulated by a professional nutritionist to meet or exceed NRC (2001) dairy requirements. The 2 diets were formulated to have
equivalent net energy content of 1.6 Mcal/kg and CP of 16.8%. Cows were paired by expected calving date, and subsequently assigned randomly to a traditional diet (TRAD) or a higher fiber, lower starch diet (HFLS), and were both fed as a TMR. Diets were composed of corn silage, chopped alfalfa hay, corn gluten feed, cottonseed, ground corn, molasses, concentrate supplements, and vitamins and minerals (Table 1). The TRAD had 20.8% less corn silage, 47.4% less alfalfa hay, 44.1% more corn grain, and 43.3% more corn gluten feed than HFLS.

Samples of the 2 diets were collected twice weekly and stored in a freezer at −20°C. For each diet, the 2 weekly samples were combined into a single weekly sample and analyzed commercially (Dairyland Laboratories Inc.) for nutrient content. The weekly results of nutrient content were averaged for months. The number of cows fed TRAD and HFLS was used to determine a weighted mean for nutrient content. Nutrient content for the duration of the study was 30.3% NDF and 23.4% starch for TRAD, and 33.6% NDF and 18.4% starch for HFLS (Table 1).

Weekly measurements for nutrient composition of diets were averaged by month, and a weighted average determined the average nutrient composition for the duration of the study. The weighted average was based on the number of cows that were fed for each diet during the respective months. The daily DMI (kg) was calculated by multiplying daily actual feed intake by the monthly DM content of the TMR diets.

A smoothing technique was applied to the daily DMI and the 7-d average of DMI around the respective DIM (46 to 147 DIM). For example, the DMI for d 46 was the average of 43, 44, 45, 46, 47, and 48 DIM. After smoothing, the daily DMI from 46 to 150 DIM was estimated by Legendre polynomial regression model within the 4 groups, by diet and breed group. The random regression models accounted for individual differences in the shape of lactation for each cow (Jamrozik and Schaeffer, 1997; Harder et al., 2019). The Legendre polynomial regressions of order 4 fit the DMI data the best when compared with order 3 and 5, and this is similar to other reported studies (Kramer et al., 2009; Harder et al., 2019).

Legendre polynomial random regression function was used to estimate 105-d lactation curves for DMI from 46 to 150 DIM with 4 parameters from PROC HPMIXED of SAS (release 9.4, SAS Institute Inc.; Kramer et al., 2009; Harder et al., 2019). The 4-parameter linear form was described by Macciotta et al. (2005) and Hurst et al. (2021) as

\[
Y_{tijk} = (\beta_0P_0t + \beta_1P_1t + \beta_2P_2t + \beta_3P_3t + \beta_4P_4t) + (\alpha_0iP_0t + \alpha_1iP_1t + \alpha_2iP_2t + \alpha_3iP_3t + \alpha_4iP_4t) + \varepsilon_{ij},
\]

where \(Y_{tijk}\) represents CFP on a given day \((t)\), \(\beta_k\) is the \(k\)th fixed regression coefficient representing the production curve of the population, and \(\alpha_{ki}\) is the \(k\)th random regression coefficient for animal \(i\). \(P_0\) to \(P_4\) are Legendre polynomial functions of order 0 to 3 and were calculated as

\[
P_0(t) = 1;
\]

\[
P_1(t) = x;
\]

\[
P_2(t) = 12 \times (3 \times x^2 - 1);
\]

\[
P_3(t) = \frac{1}{2} \times (5x^3 - 3x);
\]

\[
P_4(t) = \frac{1}{8} \times (35x^4 - 30x^2 + 3),
\]

where \(x\) is the unit of time as defined as \(x = -1 + 2 \times [(t - t_{\text{min}})/(t_{\text{max}} - t_{\text{min}})]\), where \(x\) is the number of days standardized to a length of 150 d and \(t\) is the DIM, and \(t_{\text{min}}\) was 46 d and \(t_{\text{max}}\) was 150 d. The random error is represented by \(\varepsilon_{ij}\). The random regression model was analyzed with PROC HPMIXED of SAS, and an unstructured covariance structure was used that estimated 16 covariance parameters which includes the residual variance. Also, lactation curves for DMI were estimated separately for each individual cow by combination of diet and breed group. Daily DMI observations were summed from 46 to 150 DIM to obtain the total DMI for each cow.

Table 1. Feed ingredients and nutrient composition of the 2 diets

| Item                     | Traditional | Higher fiber, lower starch |
|--------------------------|-------------|----------------------------|
| Ingredient (% of DM)     |             |                            |
| Alfalfa hay              | 9.7         | 14.3                       |
| Corn silage              | 35.5        | 42.9                       |
| Corn gluten feed         | 9.0         | 5.1                        |
| Corn grain, ground       | 18.8        | 10.5                       |
| Cottonseed, fuzzy        | 5.8         | 5.8                        |
| Molasses, liquid         | 5.0         | 5.9                        |
| Protein mix              | 15.4        | 14.1                       |
| Energy Booster 100\(^1\) | 0.7         | 1.3                        |

| Nutrient composition (% of DM) |          |          |
|-------------------------------|----------|----------|
| DM                            | 52.7     | 49.8     |
| CP                            | 15.3     | 14.8     |
| ADF                           | 21.8     | 25.0     |
| NDF                           | 30.3     | 33.6     |
| Starch                        | 23.4     | 18.4     |
| NE\(_{\text{L}}\) (Mcal/kg of DM) | 1.6   | 1.6      |

\(^1\)Hydrogenated fat (Milk Specialties).
**Production**

Cows were milked twice daily at 0330 and 1530 h in a double 5-herringbone parlor. Daily milk production was the sum of the morning and evening milking. Missing observations were estimated from the mean of 1 d before and 1 d after a missing daily milk observation. If 2 consecutive d had missing observations, daily milk production was estimated from the mean of 2 d before and 2 d after the missing daily milk observations. A similar approach was used when 3 or 4 consecutive d had missing observations for daily milk. Fat, protein, and lactose percentage were from twice monthly DHI samples (Minnesota DHIA, Buffalo, MN). Legendre polynomial random regression function was used to estimate 105-d lactation curves for daily CFP from 46 to 150 DIM with 3 parameters from PROC HPMIXED of SAS. The 3-parameter linear model was

\[ Y_{tijk} = (\beta_0P_0 + \beta_1P_1 + \beta_2P_2 + \beta_3P_3) + (\alpha_0iP_0 + \alpha_1iP_1 + \alpha_2iP_2 + \alpha_3iP_3) + \varepsilon_{ij}, \]

where \(Y_{tijk}\) represents CFP on a given day (t), \(\beta_k\) is the kth fixed regression coefficient representing the production curve of the population, and \(\alpha_{ki}\) is the kth random regression coefficient for animal I, \(P_0\) to \(P_3\) are Legendre polynomial functions of order 0 to 3 and were calculated as

\[ P_0(t) = 1; \]
\[ P_1(t) = x; \]
\[ P_2(t) = 12 \times (3 \times x^2 - 1); \text{ and} \]
\[ P_3(t) = \frac{1}{2} \times (5x^3 - 3 \times x), \]

where x is the unit of time as defined as \(x = -1 + 2 \times [(t - t_{\min})/(t_{\max} - t_{\min})]\), where x is the number of days standardized to a length of 150 d and t is the DIM, and \(t_{\min}\) was 46 d and \(t_{\max}\) was 150 d. The random error is represented by \(\varepsilon_{ij}\) (Hurst et al., 2021). Again, the random regression model was analyzed with an unstructured covariance structure that estimated 11 covariance parameters that includes the residual variance. The CFP lactation curves were estimated separately for each individual cow by combination of diet and breed group. Daily CFP observations were subsequently summed from 46 to 150 DIM to determine total CFP for each cow.

**BW and BCS**

The BW and BCS were recorded once weekly. The BW was recorded on individual cows with an electronic scale as cows exited the milking parlor during the morning milking. The BCS was recorded by one person throughout the study on a 5-point scale with 1 = thin and 5 = fat, as described by Wildman et al. (1982). Legendre polynomial random regression was used to estimate 105-d lactation curves for BW and BCS from 46 to 150 DIM with 3 parameters from PROC HPMIXED of SAS, as described above. The BW and BCS lactation curves were estimated separately for each individual cow by combination of diet and breed group. Body weight and BCS observations were the average from 46 to 150 DIM.

**Feed Efficiency and RFI**

Two measures of feed efficiency were used to compare the CB and HO cows that were fed TRAD and HFLS, and they were the ratio of 105-d CFP divided by 105-d DMI (CFP/DMI) and the ratio of 105-d DMI divided by mean BW (DMI/BW) of each cow from 46 to 150 DIM.

The regression coefficients (energy sinks) to estimate RFI of cows were energy expended in milk (MilkE), metabolic BW (MBW), and the energy for BW change (BWCE; Hardie et al., 2015; Shonka-Martin et al., 2019b). The MilkE was estimated according to the NRC (2001) as MilkE = 9.29 × fat (kg) + 5.63 × protein (kg) + 3.95 × lactose (kg). Legendre polynomial random regression was used to estimate 105-d lactation curves for MilkE from 46 to 150 DIM with 3 parameters from PROC HPMIXED of SAS, as described above.

The MilkE lactation curves were estimated separately for each individual cow by combination of diet and breed group. Estimates for daily MilkE were summed from 46 to 150 DIM to determine total MilkE for each cow. The MBW reflected the maintenance requirements for a cow and was calculated as BW\(^{0.75}\) with the mean BW of each cow from 46 to 150 DIM. The BWCE was estimated as BWCE (Mcal/d) = BWC (kg/d) × (2.88 + 1.026 × BCS) × 0.85 (NRC, 2001; Hardie et al., 2015; Shonka-Martin et al., 2019b). The BWCE used BCS to account for the energy expended for body weight change; however, BWCE does not account for the energy expended for BW maintenance. The BCS was the mean BCS of each cow from 46 to 150 DIM. The MilkE, MBW, and BWCE were energy sinks in the statistical model to estimate RFI. Cow\(_{ij}\) was the ith random regression coefficient of the jth cow, and...
an unstructured covariance structure was used for the random cow effect in PROC HPMIXED of SAS.

The RFI was defined as the error term ($\varepsilon_i$) from the regression model:

$$DMI_i = \beta_0 + \beta_1 \times \text{MilkE}_i + \beta_2 \times \text{MBW}_i + \beta_3 \times \text{BWCE}_i + \varepsilon_i,$$

where $DMI_i$ is the total DMI from 46 to 150 DIM for the $i$th cow; $\beta_0$ is the intercept; and $\beta_1$, $\beta_2$, and $\beta_3$ are the regression coefficients for MilkE, MBW, and BWCE from 46 to 150 DIM, respectively. All CB and HO cows were analyzed simultaneously, which is similar to Lu et al. (2015).

Previous research with CB and HO cows suggested that partial regression coefficients of DMI on the energy sinks of MilkE, MBW, and BWCE were different for alternative stages of lactation (Shonka-Martin et al., 2019b). Furthermore, Liu and VandeHaar (2020) reported partial regression coefficients differed for peak and late stages of lactation. Therefore, RFI was estimated separately for 5 stages, with 21-d intervals, to compare CB and HO cows from 46 to 150 DIM. The energy sinks were based on mean MilkE, MBW, and BWCE within each 21-d interval for each cow. The RFI for 21-d intervals was estimated with the same model that was previously used for estimation of RFI from 46 to 150 DIM.

**RESULTS AND DISCUSSION**

**Diet**

Across breed groups, cows fed TRAD had higher ($P < 0.05$) DMI, DMI/BW, and BWCE (2,514 kg, 4.32, 394 Mcal, respectively) than cows fed HFLS (2,254 kg, 3.92, 320 Mcal, respectively). The cows fed TRAD and HFLS were not different for CFP, BW, BCS, CFP/DMI, MilkE, MBW, and RFI. The significant difference of TRAD and HFLS cows for DMI may have been because the DMI was regulated by the physical capacity of the rumen (Allen, 2000). Boerman et al. (2015) reported mid-lactation cows fed a higher starch diet (27.2% NDF and 30.1% starch) had more DMI (28.0 vs. 26.4 kg/d, respectively) than cows fed a lower starch diet (43.9% NDF and 12.2% starch), because the cows fed the higher starch diet were not limited by physical rumen fill. In the United Kingdom, CB and HO cows had more DMI (14.9 vs. 17.2 kg/d, respectively) but similar BW and BCS when fed an increased proportion (30 or 70%) of concentrates in the diet (Xue et al., 2011). Pasture-based cows fed a high-concentrate diet had a BW of 10 kg more and higher BCS than pasture-based cows fed a low concentrate diet (Walsh et al., 2008). Mid-lactation HO cows fed a higher starch (30%) diet partitioned more energy (3.76 vs. 2.04 Mcal/d, respectively) to body tissue gain than HO cows fed a lower starch (14%) diet (Potts et al., 2017).

**Breed Group**

Across the 2 diets, the CB cows (3.64) had higher ($P < 0.05$) BCS than HO cows (3.10) and the CB cows had more ($P < 0.05$) BWCE than HO cows (412 vs. 303 Mcal). The CB and HO cows were not different for DMI, CFP, BW, CFP/DMI, DMI/BW, MilkE, MBW, and RFI. As expected, the CB cows had higher BCS than HO cows (Heins et al., 2008; Xue et al., 2011; Hazel et al., 2013; Shonka-Martin et al., 2019a). The CB cows had more BWCE compared with HO cows; however, the CB and HO cows were not different for DMI (2,357 vs. 2,411 kg, respectively) and CFP (256 vs. 263 kg, respectively). In a similar study, 3-breed CB cows of MO, VR, and HO breeds were not different for BWCE compared with HO cows fed a TMR diet that was similar to TRAD in this study (Shonka-Martin et al., 2019b). Less BWCE indicated cows had little change in BW, so more energy from feed intake is required for BW gain than is recovered from loss of BW (O’Mara, 2000; Coleman et al., 2010).
Breed Group and Diet for DMI, CFP, BW, BCS, and Feed Efficiency

The least squares means (LSM) and standard error of the mean (SEM) from 46 to 150 DIM of DMI, CFP, BW, BCS, CFP/DMI, and DMI/BW for breed groups by diet are in Table 2. The P-values for the main effects of diet and breed group as well as diet by breed group interaction are also in the table. The HO cows fed TRAD (2,592 kg) had more (P < 0.05) DMI than HO cows fed HFLS (2,229 kg) and CB cows fed HFLS (2,278 kg). The CB and HO cows that were fed TRAD and HFLS were not different for DMI. The CB and HO cows were not different across diets for CFP. The CB cows fed HFLS had more (P < 0.05) BW (+50 kg) compared with HO cows fed HFLS. The BW did not differ for CB and HO cows that were fed TRAD. The BCS was higher (P < 0.05) for CB cows fed either TRAD or HFLS compared with HO cows fed either TRAD or HFLS. The CB cows were not different for BCS whether fed TRAD or HFLS, and the HO cows were not different for BCS across the 2 diets. The HO cows fed TRAD had lower (P < 0.05) CFP/DMI compared with HO cows fed HFLS. The CB cows fed TRAD and HFLS and HO cows fed HFLS were not different for CFP/DMI. The CB cows fed HFLS (3.80) had lower (P < 0.05) DMI/BW compared with HO cows fed TRAD (4.43) and CB cows fed TRAD (4.21). The CB cows fed TRAD had greater (P < 0.05) change in BW compared with HO cows fed TRAD and HO cows fed HFLS. Furthermore, CB cows fed TRAD had greater (P < 0.05) change in BCS compared with HO cows fed HFLS.

Heins et al. (2008) and Hazel et al. (2013) reported CB cows were not different from HO cows for DMI during the first 150 d of first lactation when fed a TMR diet similar to the TRAD. Conversely, 3-breed rotational CB cows of MO, VR, and HO had less DMI than HO cows (2,807 vs. 2,948 kg, respectively) during the first 150 d of first lactation (Shonka-Martin et al., 2019b). Similar to the current study, HO cows fed a higher forage, lower starch diet (36% NDF, 19% starch) had less DMI compared with HO cows (22 vs. 24.4 kg/d, respectively) fed a lower forage higher starch diet (26% NDF, 32% starch; Carrasquillo-Mangual, 2017). The CB and HO cows that were fed diets with alternative levels of concentrate did not differ for CFP for pasture-based herds (Walsh et al., 2008; Vance et al., 2013; Ferris et al., 2018). Furthermore, Heins et al. (2008) and Hazel et al. (2013) found CFP did not differ for cows fed TRAD during the first 150 d of first lactation.

Similar to the current study, CFP/DMI was not different for JE × HO (0.094) and HO cows (0.093) from

### Table 2

| Variable          | Traditional | Higher fiber, lower starch | Diet × breed group | P-value |
|-------------------|-------------|---------------------------|--------------------|---------|
| DMI (kg)          | 2,592.<sup>a</sup> | 2,436.<sup>ab</sup>     | 0.02               | 0.56    |
| CFP (kg)          | 269         | 256                       | 0.32               | 0.34    |
| BW (kg)           | 586.<sup>ab</sup> | 576.<sup>ab</sup>       | 0.70               | 0.30    |
| BCS               | 3.19.<sup>a</sup> | 3.64.<sup>b</sup>       | 0.26               | 0.01    |
| CFP/DMI           | 0.10.004    | 0.12.004                 | 0.06               | 0.90    |
| DMI/BW            | 4.43.0129   | 4.21.0129                | 0.01               | 0.94    |
| BWΔ (kg)          | 56.9.0458   | 73.17.0458               | 0.04               | 0.98    |
| BCSΔ              | 0.21.005    | 0.36.005                 | 0.48               | 0.02    |

*Means within a row with different superscripts differ (P < 0.05).

The BW and BCS are means across the 105-d period and DMI are total DMI from 46 to 130 DIM.
4 to 150 DIM during first lactation (Heins et al., 2008). Three-breed CB cows of MO, VR, and HO had higher CFP/DMI (0.119 vs. 0.113, respectively) and lower DMI/BW (5.035 vs. 5.314, respectively) than HO cows during the first 150 d of first lactation (Shonka-Martin et al., 2019b).

The CB cows may have used DMI beyond their needs for production and maintenance for higher BCS. This study only investigated 46 to 150 DIM of first lactation, and additional research is needed to compare multiple lactations of CB and HO cows across 305 d. Dairy producers initially moved to CB cows to improve health and fertility; however, dairy producers may improve efficiency and the economics of dairying with CB cows fed higher forage, lower starch diets.

**Breed Group and Diet for RFI**

The statistical model with the fixed effects of MilkE, MBW, and BWCE explained 69% of the variation in DMI. The partial regression coefficients of DMI on MilkE, MBW, and BWCE were 0.85, 14.41, and 0.79, respectively, and the MilkE and MBW explained significant ($P < 0.05$) variation of DMI. The BWCE tended ($P < 0.10$) to explain variation of DMI. The partial regression coefficients were similar to those of Shonka-Martin et al. (2019b) who reported coefficients of 0.75, 8.45, and 0.62 for MilkE, MBW, and BWCE, respectively, for 3-breed rotational CB cows of MO, VR, and HO, and HO cows that were fed the same diet. The partial regression coefficient for MBW in the current study was higher than that reported by Shonka-Martin et al. (2019b). For recent research with HO cows, Lu et al. (2015) reported regression coefficients of 0.6 for MilkE and 0.2 for MBW, and Tempelman et al. (2015) reported 0.29 for MilkE and 0.06 to 0.16 for MBW. For HO cows fed low and high protein diets, Liu and VandeHaar (2020) reported 0.37 to 0.44 for MilkE, 0.06 to 0.08 for MBW, and 0.03 to 0.05 for BWCE. A research study of over 5,000 cows from 13 research stations in 4 countries reported regression coefficients range 0.28 to 0.47 for MilkE and 0.07 to 0.21 for MBW (Lu et al., 2017). Regression coefficients from the current study are slightly higher for MilkE and BWCE compared with the previously reported studies from HO cows. However, regression coefficients are larger for MBW compared with previous HO studies and, perhaps, reflect a change of metabolic status for the HO and CB cows in the current study.

The LSM and SEM from 46 to 150 DIM for MilkE, MBW, BWCE, and RFI for breed groups by diet are in Table 3. The $P$-values for the main effects of diet and breed group as well as diet by breed group interaction are also in the table. Within breed group, neither the CB nor the HO cows that were fed either TRAD or HFLS were different for MilkE. The CB cows that were fed HFLS (121 kg) had more ($P < 0.05$) MBW compared with HO cows that were fed HFLS (114 kg). The CB cows that were fed either TRAD or HFLS had more ($P < 0.05$) BWCE than HO cows that were fed HFLS. The HO cows fed TRAD had more ($P < 0.05$) BWCE compared with HO cows that were fed HFLS. The RFI was lower ($P < 0.05$) for CB cows that were fed HFLS ($−120.0$ kg) compared with the HO cows that were fed TRAD ($+85.3$ kg), and less RFI is favorable. The percentage of Feed Saved was $−1.2\%$ for CB cows fed TRAD, $0.8\%$ for HO cows fed HFLS, and $−5.7\%$ for CB cows fed HFLS. However, the HO cows fed TRAD required 3.1% more feed and would not save any feed. Figure 1 has the mean RFI and predicted DMI of the CB and HO cows fed HFLS and TRAD. The most favorable cows for RFI were CB cows fed HFLS (5 of 9 cows) and the least favorable cows for RFI were HO cows fed HFLS fed TRAD (7 of 11 cows). The CB cows fed HFLS had lower mean RFI than HO cows fed TRAD but did not differ for MilkE, MBW, and BWCE. Furthermore, CB cows fed HFLS consumed less DMI than HO cows fed TRAD. The more favorable RFI for the CB cows fed HFLS met expectations because the CB cows that were fed HFLS had less DMI ($−314$ kg) and had lower DMI/BW ($−0.63$) than HO cows that were fed TRAD. Similarly, Shonka-Martin et al. (2019b) reported 3-breed rotational CB cows of MO, VR, and HO had a lower mean RFI ($−65.5$ vs. $+68.8$ kg) than HO cows during the first 150 d of first lactation.

The RFI was estimated with the CB and HO cows combined, because when RFI was estimated by diet or by diet and breed group combination, the partial regression coefficients for MBW and BWCE were negative, which contradicted biological expectation and was incongruous. Furthermore, partial regression coefficients for DMI on MBW and BWCE estimated by CB and HO cows separately were opposite in direction and not significant. The HO and CB cows fed HFLS consumed significantly less DMI than HO cows fed TRAD, which may have contributed to the illogical estimates for the partial regression coefficients when estimated separately by breed group or diet. The partial regression coefficients for cows fed TRAD ranged 0.237 to 0.835 for MilkE, 15.43 to 25.59 for MBW, and $−0.303$ to 1.18 for BWCE, and the partial regression coefficients for cows fed HFLS ranged $−0.839$ to 0.649 for MilkE, 8.68 to 20.07 for MBW, and $−3.73$ to 2.71 for BWCE. Because of these inconsistent estimates, RFI was estimated for the CB and HO cows combined.

Voelker et al. (2002) reported energy expended in milk (MilkE) was higher for multiparous HO cows fed a lower forage diet compared with HO cows fed a higher
forage diet (22.8 vs. 21.6 Mcal/d, respectively). Vance et al. (2012) found JE × HO cows partitioned more energy to body tissue gain rather than to milk production in mid to late lactation fed higher concentrate diets compared with lower concentrate diets. Unlike the HO cows, the JE × HO cows perhaps did not use the additional nutrients and energy in high-concentrate diets for milk production (Vance et al., 2012, 2013). Cows that have more BW may have higher maintenance requirements (Ferris et al., 2018). In the current study, the CB cows fed HFLS may have had more maintenance requirement for BW; however, CFP and MilkE were not different for the CB and HO cows. Colinearity between BCS, MilkE, MBW, and BWCE may not have existed in the current study, because of low to moderate correlations between BCS and energy sinks. The Pearson correlation for BCS and MBW was moderately correlated (0.43) and the Pearson correlation between BCS and BWCE was 0.57 and, perhaps, BCS was partially accounted for in RFI with the BWCE energy sink.

The partial regression coefficients for DMI on MilkE and MBW were all positive and significant in each interval (P < 0.05), except for MBW in interval 4 (P = 0.12). For BWCE, the partial regression coefficients were positive (range was 0.57 to 0.86) and were not significant (P = 0.06 to 0.18). Estimated partial regression coefficients of DMI on MilkE were lowest in interval 1, which was similar to coefficients reported by Shonka-Martin et al. (2019b) for HO and CB cows. Overall, the partial regression coefficients of DMI on MilkE by 21-d interval in our study were slightly higher than those estimated in recent studies (Liu and VandeHaar, 2020). The partial regression coefficients for DMI on MBW for 21-d intervals were greater in the current study (1.99 to 4.02) compared with Shonka-Martin et al. (2019b) for HO and CB cows. Furthermore, the partial regression coefficients for DMI on BWCE were similar to those reported by Shonka-Martin et al. (2019b) for HO and CB cows, but they were higher than those of Potts et al. (2017) for DMI on BWCE. Partial regression coefficients may differ by research study because of diets fed to cows and may differ among cows at the same location of study (Liu and VandeHaar, 2020), so partial regression coefficients across feed intake studies may be difficult to interpret and compare. Furthermore, partial regression coefficients are not constant across a lactation, because cow BW may change drastically from early lactation to late lactation (Li et al., 2017).

The CB cows fed HFLS had lower (P < 0.05) RFI for each 21-d interval than HO cows fed TRAD (Figure 2) and RFI decreased with increasing intervals. The difference of diets and breeds for RFI followed a similar pattern to the RFI from 46 to 150 DIM, with differences for CB cows fed HFLS and HO cows fed TRAD. For determination of RFI, energy sinks often include MilkE, MBW, and change in BW to account for body tissue mobilization. Potts et al. (2017) postulated that body tissue mobilization and the energy related to body maintenance may account for substantial variation in RFI. The RFI for CB cows may be different than HO cows because of MBW and BWCE, because numerous studies have reported no difference in production of HO cows and CB cows composed of HO, MO, and VR and HO cows (Hazel et al., 2021; Shonka-Martin et al., 2019a; Heins and Hansen, 2012; Heins et al., 2008). Perhaps, CB cows mobilize body tissue differently than HO cows, which may affect energy balance. Energy balance is related to metabolic diseases, and CB cows have less incidence of metabolic diseases than HO cows (Hazel et al., 2021). The RFI model may not adequately

| Variable | Holstein | Montbéliarde × Viking Red × Holstein | Montbéliarde × Viking Red × Holstein | Diet × Breed | P-value |
|----------|----------|-------------------------------------|-------------------------------------|-------------|---------|
| MilkE (Mcal) | 2,808 ± 74.8 | 2,651 ± 82.7 | 2,645 ± 87.8 | 2,610 ± 87.8 | 0.23 ± 0.26 ± 0.47 |
| MBW (kg<sup>0.75</sup>) | 119 ± 2.3 | 117 ± 2.5 | 114 ± 2.7 | 121 ± 2.7 | 0.73 ± 0.31 ± 0.08 |
| BWCE (Mcal) | 342 ± 24.8 | 447 ± 27.4 | 29 ± 29.0 | 377 ± 29.0 | 0.01 ± 0.01 ± 0.89 |
| RFI<sup>a</sup> | 85.4 ± 56.7 | 0.8 ± 62.7 | 1.8 ± 66.5 | −120.0 ± 66.5 | 0.12 ± 0.11 ± 0.77 |

<sup>a</sup>Means within a row with different superscripts differ (P < 0.05).

<sup>1</sup>Milk energy output (MilkE in Mcal) = [9.29 × fat (kg) + 5.63 × protein (kg) + 3.95 × lactose (kg)].

<sup>2</sup>Metabolic body weight (MBW in kg<sup>0.75</sup>) = mean BW<sup>0.75</sup> from 46 to 150 DIM.

<sup>3</sup>Change in body weight energy (BWCE in Mcal) = [BCW × (2.88 + 1.026 × mean BCS from 46 to 150 DIM) × 0.85].

<sup>4</sup>RFI is the error term from the regression model that accounted for MilkE, MBW, and BWCE for 46 to 150 DIM.
account for energy partitioning of cows, because energy requirements are different for fat (kg) compared with protein (kg) production. Furthermore, the prediction equations for DMI used to determine RFI are often based on HO cows and may not be appropriate for CB cows because CB cows may differ from HO cows for fat deposition, heat production, body maintenance, body shape, and DMI.

Figure 1. Residual feed intake (RFI) plotted against predicted DMI from 46 to 150 DIM of primiparous cows. The horizontal lines represent the mean RFI for each of the diet and breed groups, and the ovals represent 95% prediction ellipses. The overall mean RFI is the horizontal solid black line. The solid circle (●), dashed horizontal line above zero, and dashed oval represent the Holstein cows fed a traditional diet (85.3 kg). The solid triangle (▲), solid black horizontal line, and solid oval represent the 3-breed rotational crossbred cows fed a traditional diet (0.8 kg). The unfilled circle (○), dash and dot horizontal line, and dash and dot oval represent the Holstein cows fed a higher fiber, lower starch diet (1.8 kg). The unfilled triangle (Δ), dotted horizontal line below zero, and dotted oval represent the 3-breed rotational crossbred cows fed a higher fiber, lower starch diet (−120.0 kg).
Energy requirements for maintenance, DMI, and milk production may change dramatically depending on the stage of lactation for cows (Coleman et al., 2010; Li et al., 2017). The RFI should be estimated with similar physiological and environmental conditions of cows. Tempelman et al. (2015) reported RFI for HO cows from 50 to 200 DIM because BW change was stable during that period of lactation. In early lactation, cows require more energy to gain BW compared with later lactation (Coleman et al., 2010). Cows may be in negative energy balance and mobilize body fat in early lactation (De Vries and Veerkamp, 2000) and, therefore, have increased variation in DMI and production. The RFI does not consider body measurements (stature, dairy strength, and body depth), fertility, and longevity. Therefore, RFI may be underestimated in the current study for CB cows compared with HO cows.

**CONCLUSIONS**

Dairy producers may feed either TRAD or HFLS to CB cows without loss of CFP. For HO cows, the DMI was less for the cows that were fed HFLS compared with the cows that were fed TRAD. Less RFI for the CB cows fed HFLS compared with the HO cows that were fed TRAD indicated that the CB cows were more feed efficient than HO cows. Genetic selection of feed-efficient cows should not be based solely on reducing DMI, but should consider BW, BCS, production, health, fertility and longevity.

**ACKNOWLEDGMENTS**

Funding for this project was provided by ProCROSS (Randers, Denmark). The authors express gratitude to the staff at the Dairy Cattle Teaching and Research Facility of the University of Minnesota, St. Paul, for their assistance in data collection and care of animals. The authors have not stated any conflicts of interest.

**REFERENCES**

Allen, M. S. 2000. Effects of diet on short-term regulation of feed intake by lactating dairy cattle. J. Dairy Sci. 83:1598–1624. https://doi.org/10.3168/jds.S0022-0302(00)75000-2.

Boerman, J. P., S. R. Potts, M. J. Vandelaar, M. S. Allen, and A. L. Lock. 2015. Milk production responses to a change in dietary...
Walsh, S., F. Buckley, K. Pierce, N. Byrne, J. Patton, and P. Dillon. 2008. Effects of breed and feeding system on milk production, body weight, body condition score, reproductive performance, and postpartum ovarian function. J. Dairy Sci. 91:4401–4413. https://doi.org/10.3168/jds.2007-0818.

Wildman, E. E., G. M. Jones, P. E. Wagner, R. L. Boman, H. F. Troutt Jr., and T. N. Lesch. 1982. A dairy cow body condition scoring system and its relationship to selected production characteristics. J. Dairy Sci. 65:495–501. https://doi.org/10.3168/jds.S0022-0302(82)82223-6.

Xue, B., T. Yan, C. F. Ferris, and C. S. Mayne. 2011. Milk production and energy efficiency of Holstein and Jersey-Holstein crossbred dairy cows offered diets containing grass silage. J. Dairy Sci. 94:1455–1464. https://doi.org/10.3168/jds.2010-3663.

ORCIDs

G. M. Pereira  https://orcid.org/0000-0002-2955-0749
B. J. Heins  https://orcid.org/0000-0003-2186-9082
L. B. Hansen  https://orcid.org/0000-0002-2752-2736