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PRODUCTION AND MANAGEMENT: *Symposium Article*

Invited Review: Connecting the dots—Calving difficulty, age at first calving, and enhanced cow production*

M. I. Marcondes,[1]† J. C. C. Chagas,[2] A. F. Kertz,[3] PAS, T. Allen,[4] and J. M. Bewley[5]
[1]William H. Miner Agricultural Research Institute, Chazy, NY 12921; [2]Department of Applied Animal Science and Welfare, Swedish University of Agricultural Sciences, Umeå, 901 83, Sweden; [3]ANDHIL LLC, St. Louis, MO 63122; [4]Agritech Analytics, Visalia, CA 93291; and [5]Holstein Association USA, Brattleboro, VT 05301

ABSTRACT

Purpose: We aimed to explore the relationships among calving difficulty (CD), production traits, age at first calving (AFC), and culling in dairy cattle.

Sources: Data from 687 US dairy farms, encompassing 1,048,574 CD observations scored from 1 to 5, were analyzed. Scores of CD 5 were adjusted to 4 due to limited interactions with other variables. The focus was on Holstein, Jersey, and dairy cross breeds, and parity was categorized as primiparous or multiparous.

Synthesis: The study comprised 4 steps. Step 1 assessed the effect of CD on milk yield, fat, protein, ECM, and peak milk production with fixed effects of CD, parity, calf sex (CS), and breed and random effects of calving year, calving season, and herd. Step 2 analyzed AFC, using linear and quadratic covariates, on the same parameters. Step 3 examined CD as the response variable in the step 2 database. Step 4 used logistic regression to assess risk factors associated with CD and culling reasons. Our results showed the following. Step 1: CD significantly affected milk yield, ECM, fat, protein, and peak milk production, with declines in production traits for CD >2, the least values at CD 4. Step 2: Significant linear and quadratic AFC covariates showed optimal milk performance at 27 to 28 mo. Step 3: CD was influenced by breed, CS, AFC, and interactions, with minimal CD observed at AFC of 23 to 26 mo. Step 4: Greater CD was linked to culling for nondairy purposes.

Conclusions and Applications: Calving difficulty affects production traits and is influenced by parity, breed, and CS, but its effect is less significant than expected. The AFC, particularly over 26 mo, has a more pronounced effect on CD. Greater CD levels are associated with increased involuntary culling.

Key words: culling, dystocia, linear models, logistic models, milk production

INTRODUCTION

Calving difficulty (**CD**) or dystocia is defined as difficulty during spontaneous calving or prolonged and assisted parturition (Mee, 2004), and it is typically scored on a scale from 1 to 5, where 1 indicates easy, unassisted calving and 5 represents extreme difficulty (Djemali et al., 1987). Dystocia remains a significant concern in dairy herds (Van Dieten, 1963; Philipsson, 1976), affecting herd profitability and animal welfare (EFSA, 2009). In the United States, the prevalence of CD in dairy herds is reported to be at 13.7% (Gevrekci et al., 2006), with mild and severe cases occurring in 10.8% of cows and 18.6% of heifers (USDA, 2007).

Johanson and Berger (2003) observed that the odds for dystocia decrease by 4.7%/yr, suggesting an expected rate of 8.1% in 2024 versus 23.7% observed in 2003. The consequences of CD include negative effects on milk yield, reproductive performance, stillbirth, cow death, retained placenta, uterine infections, increased involuntary culling, veterinary fees, and extra labor (Barrier and Haskell, 2011; Ghanem et al., 2013; Zobel, 2013; Kaya et al., 2015). Dematawena and Berger (1997) found that a CD = 5, compared with a score 1, resulted in a reduction in 305-d milk yield by 703.6 kg, milk fat by 24.1 kg, and protein by 20.8 kg, while increasing days open by 33 d, the number of services by 0.2, and cow losses by 4.1%. Barrier and Haskell (2011) reported that CD severity affects milk production in Holstein-Friesian herds in Scotland, with assisted calving leading to a 31% decrease in milk yield for

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†Corresponding author: mmarcondes@whminer.com

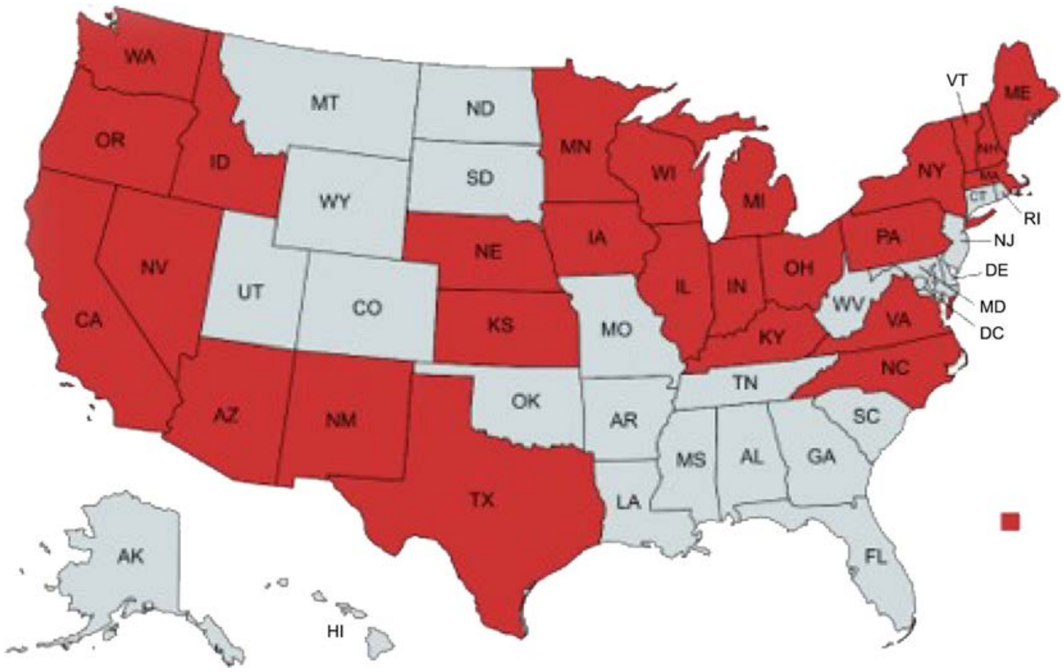

Figure 1. The US states highlighted in red indicate the origin of the data inputs.

cows up to 90 DIM, and an estimated daily milk loss of 1.65 L/d for cows up to 60 DIM.

Factors influencing milk loss patterns include overall yield, cow parity, scoring methods, genetics, livestock management, and calving practices (Mangurkar et al., 1984; Rajala and Grohn, 1998; Barrier and Haskell, 2011). Given advancements in cattle management and genetics, many of these estimates are outdated, necessitating updated data to better understand the long-term effects on production and culling (Roche et al., 2023).

To better contextualize the connections among CD, age at first calving (**AFC**), and enhanced cow production, it is crucial to understand how these factors interact to influence long-term herd performance. Calving difficulty, as mentioned previously, is often associated with greater calf mortality, reduced reproductive performance, and increased culling rates, all of which negatively affect production efficiency. Meanwhile, AFC is critical in determining lifetime milk production and longevity, with earlier calving typically linked to greater lifetime yields and extended productive periods (Ettema and Santos, 2004). Properly managing both CD and AFC can significantly enhance dairy cow productivity by improving health, fertility, and milk yield. Additionally, other factors such as breed, calf sex (**CS**), parity, and involuntary culling also influence production outcomes. A modeling approach using mixed and logistic models has been employed to study how these variables interact with CD, offering a deeper understanding of the combined effects on overall herd productivity. This study was developed in 4 steps with the following hypotheses: (1) greater CD scores result in lesser milk production and quality; (2) younger heifers experience more calving difficulties and, consequently, lesser milk yield; and (3) cows with greater CD scores are more likely to be involuntarily culled.

MATERIALS AND METHODS

Data Source

Data investigated in this study were provided by Agri-Tech Analytics and originated from 687 dairy farms in the United States; of these, 65% of the herds were from California, whereas the remaining data came from 25 states ranging from the Pacific Northwest all the way to Maine (Figure 1). The data set comprised 1,048,574 calving observations collected between 2009 and 2023.

On farm, animals were scored for calving difficulty as proposed by Djemali et al. (1987): 1 = easy unassisted calving; 2 = easy pull; 3 = hard pull; 4 = veterinary assistance; 5 = extreme difficulty or cesarean section.

Database Adequacy

Milk production data assessed were best-predicted 305-d milk yield (**MY**), fat, protein, ECM, and milk yield at lactation peak (**MLP**), which were first converted from pounds to kilograms. Observations for multiparous cows with parity >15 and cows carrying twins or triplets were deleted, as well as those for breeds other than Holstein, Jersey, and dairy crosses (majority of Holstein-Jersey crossbreds and limited information of these breeds crossed with other dairy breeds; **XD**). Outliers were excluded at the 1% of both tails of all variables and accessed by PROC UNIVARIATE in SAS v9.4 (SAS Institute Inc.). Farms identified with wrong CD score registrations were also excluded (e.g., farms reporting only CD = 1 records). Parity

Table 1. Qualitative and quantitative (kg) description of variables related to the effects of caving difficulty on milk yield and composition for dairy cattle

Item	Category	Observations (no.)	Mean	SD	Minimum	Maximum
Qualitative variable						
Calving difficulty						
	1	328,150				
	2	36,144				
	3	25,202				
	4	5,705				
Calf sex						
	Male	316,717				
	Female	449,022				
Calving season						
	Spring	189,441				
	Summer	199,936				
	Fall	197,394				
	Winter	208,102				
Cow breed						
	Holstein	412,708				
	Jersey	246,638				
	Dairy crosses	129,380				
Parity						
	Primiparous	130,998				
	Multiparous	663,875				
Quantitative variable						
Age at first calving		128,092	22.3	2.05	19.3	30.2
Milk yield[1]		794,873	10,841	2,222	6,094	16,382
Fat[1]		794,873	452	73.7	168	939
Protein[1]		794,850	361	56.8	133	594
Milk yield at lactation peak		794,873	44.8	10.52	18.5	73.2

[1]Best-predicted 305-day yield.

was categorized as primiparous (parity = 1) or multiparous (parity ≥2). Calving difficulty score 5 was considered as 4 due to the inexistence of interactions of CD = 5 with most of the independent variables studied, such as parity, breed, CS, calving year (**CY**), calving season, and herd. Adequacy adjustments to the main database resulted in a new data set composed of 465,114 CD valid observations. Scores 1, 2, 3, and 4/5 had a respectively frequency of observation of 82.6%, 9.20%, 6.57%, and 1.58%.

Data Evaluation

All the variables studied are statistically described in Table 1 and were evaluated by PROC MEANS and PROC FREQ in SAS. The study was developed in 4 steps, as described in the following. For the statistical analyses in steps 1 to 3, data were subjected to ANOVA using PROC GLIMMIX in SAS.

Step 1: Effects of CD on Milk Production Traits. For step 1, we adopted the main database with 465,114 CD observations. The effects of CD on milk production parameters such as MY, milk fat, milk protein, ECM, and MLP was studied. Calving difficulty scores, parity, CS, breed, and all their interactions were set as fixed effects in the model, and CY, calving season, and herd were set as random effects. The model was refined using backward selection, with a threshold of $P > 0.05$ for removing variables. The final parameters were generated from this reduced model, where all remaining variables were significant at $P < 0.05$. No trends were applied in this study.

Step 2: Effects of CD on Milk Production Traits with AFC as Covariate. Second, an AFC database was created using the same criteria as in step 1 but exclusively retaining data from primiparous cows. This adjustment was necessary because we only had AFC data for primiparous cows. Additionally, XD were excluded due to insufficient data on the interaction between AFC and CD, and AFC values outside the range of 19.27 to 30.26 (outliers at the 1% tail level) were also excluded, resulting in 90,718 CD observations. For this step, AFC was included as both linear and quadratic covariate components in the model. The same parameters were evaluated as in step 1, with the same fixed and random effects considered. However, only primiparous was used, resulting in the exclusion of parity.

Table 2. Reasons-for-leaving-the-herd variables related to the effects of caving difficulty on milk yield and composition for dairy cattle

Item	Observations (no.)
Dairy purpose	72,315
Low production	90,637
Reproduction	23,113
Sold not specific	64,642
Died	33,313
Sickness[1]	41,967

[1]Lameness, mastitis, and udder and lactation problems.

The final model was generated using the same backward approach described in step 1.

Step 3: CD as Response Variable. In step 3, by adopting a modeling approach, CD was studied as the response variable using the same database as in step 2. Age at first calving was included in the model as linear and quadratic components, treated as fixed effects, together with CS, and breed. The model included CY, calving season, and herd as random effects. Because CD is a noncontinuous variable, we tested all possible distributions available in PROC GLIMMIX to identify the best fit for our database, using Akaike information criterion for selection. Ultimately, the normal distribution provided the best fit and was used for all evaluations in this step.

Step 4: Logistical Regression to Study Risk Factor Associations with CD and Reasons for Culling. In step 4, data were accessed to study risk factors associated with CD and reasons for culling in dairy herds. On farm, culling reasons were registered as "dairy purpose," low production, reproduction, sold not specified, died, mastitis, lameness and others. To ensure data adequacy, mastitis, lameness, and lactation and udder problems (because of nonspecific sickness) were grouped together and categorized as general sickness, resulting in a new database. Number of observations for reasons for culling are presented in Table 2. Data were processed by adopting PROC LOGISTIC in SAS. The results were generated using CD as the response variable, altering the reference reason for culling to explore the relationship between culling and CD. A significance level was set at $P < 0.05$.

RESULTS AND DISCUSSION

In step 1, when studying CD affecting milk performance, MY was not affected by the 4-way interaction ($P = 0.09$; Supplemental Material, see Notes) or any 3-way interactions ($P > 0.05$); however, it was affected by several 2-way interactions: (1) CD × breed ($P < 0.01$), (2) CD × parity ($P = 0.03$), (3) breed × CS ($P < 0.01$), and (4) parity × breed ($P < 0.01$). In this study we were focusing on CD; those interactions of interest are represented in Figure 2a and 2b. Calving difficulty affected differently primiparous and multiparous cows. In primiparous cows, there was a 1.7% decrease in MY with each additional score in CD, whereas in multiparous cows, there was an increase of 0.3% in MY from CD 1 to 2 and then a linear decrease of 1.1% for each additional CD score. This indicates that CD $\geq$3 shows a negative consequence for that current lactation. It is interesting to note that milk yield improved from CD 1 to 2 in multiparous cows. There is strong evidence that high-producing dairy cows are more susceptible to dystocia due to factors such as larger calf birth weights and genetic selection favoring milk yield over calving ease (Roche et al., 2023). This same study showed that cows experiencing difficult calvings face long-term issues such as reduced milk yield, greater rates of postpartum disease, and an increased likelihood of being culled. Interestingly, these cows can achieve optimal production if dystocia levels can be managed to a CD score of 2 or less. However, if dystocia is not controlled, it can have detrimental effects on overall performance. Improved breeding practices and better management strategies are critical for minimizing dystocia and enhancing both animal welfare and farm profitability. Thus, balancing genetic selection for calving ease with high milk production is essential for ensuring the health and sustainability of dairy herds. Still, regarding the CD × parity interactions, we observed that the overall effect of parity on CD is weaker than other interactions, such as breed. This suggests that the CD × parity interaction may be less significant than other factors discussed in this study. Additionally, the variation in MY across different lactations in multiparous cows may contribute to this weaker effect. Initially, we attempted to subdivide multiparous cows into groups based on 2, 3, or 4+ lactations and even considered dividing them into 2 and 3+ lactations. However, due to insufficient replications within each interaction group, the resulting data were inadequate for a robust analysis and produced unrealistic results. As a result, we chose to simplify the comparison to primiparous versus multiparous cows. Future studies with larger data sets should address this issue to provide more comprehensive insights into these interactions.

Initially, we suspected a correlation between CD and MY, where higher-producing cows tend to have more calving problems. Consequently, genetic improvements aimed at increasing milk yield might also lead to an increase in CD within the herd. However, according to the Council on Dairy Cattle Breeding (2020), PTA values for calving difficulty have been decreasing from 2000 to 2014 (10% to 8% PTA for CD in Holstein cattle), suggesting that previous values might have been overestimated and current values should be lesser. In line with this, our study observed that in CD observations from 2013 to 2023, there was an average annual increase of 2.8% in the frequency of eutocia (CD = 1). Consequently, the total frequency of CD score 1 increased from 70.3% to 92.5% compared with other scores. This increase is likely attributable to a better understanding of cow physiology and improved

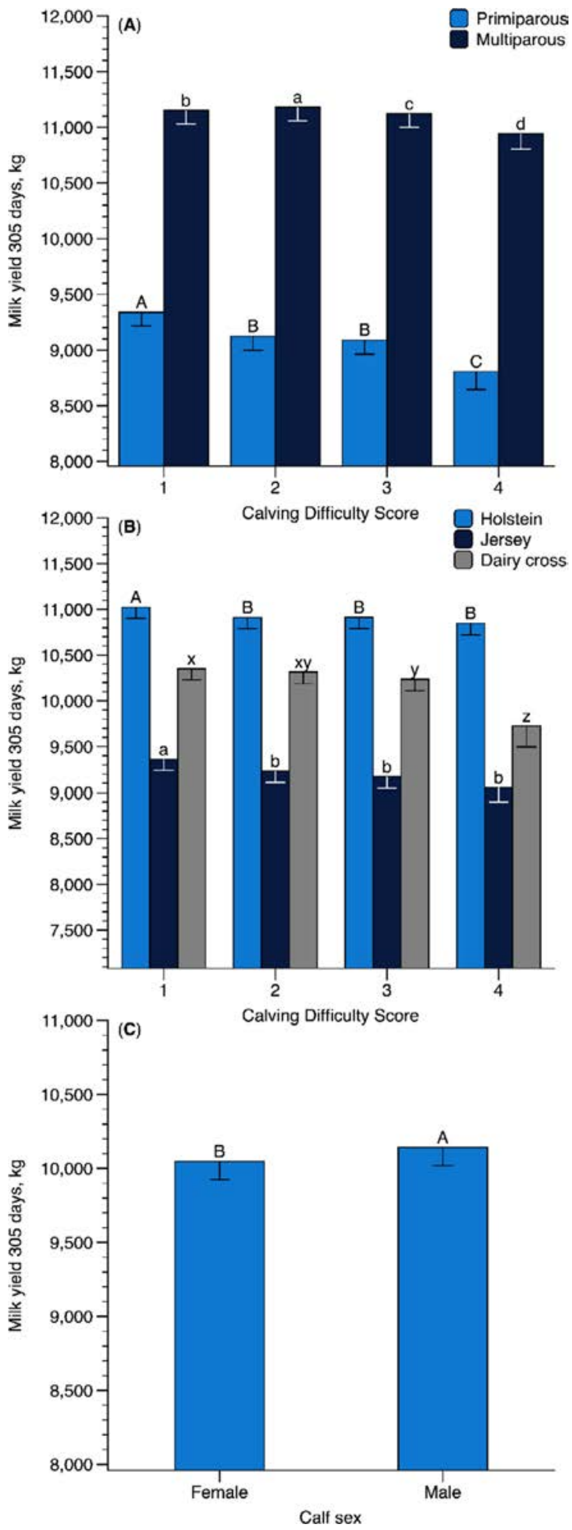

Figure 2. Effects of parity (primiparous and multiparous), breed, calf sex, and their interaction with caving difficulty on best-predicted 305-day milk yield in US dairy herds. Bars represent mean ±SE. (A) Different uppercase letters (A–C) and lowercase letters (a–d) compare calving scores within lactation number (means with different letters are significantly different, $P < 0.05$). (B) Different uppercase letters (A, B), lowercase letters (a, b), and lowercase letters (x–z) compare calving scores within breed ($P < 0.05$). (C) Different uppercase letters (A, B) compare calf sex ($P < 0.05$).

management practices by dairy farmers. Additionally, using sensors to predict time to calving and general health has probably played a significant role in decreasing CD.

Regarding breed, there was a decrease in MY when CD went from 1 to 2 in Holsteins and Jerseys but no further decrease with greater CD levels. Nevertheless, with XD, there was a slight reduction in MY from CD 1 to 3 but a more intensified decrease from CD 3 to 4. Calving difficulty might be more intense in crossbred cattle than in purebred cattle due to several factors. One significant factor is heterosis; although it generally leads to improved overall performance, it can also result in larger birth weights and increased gestation lengths, both of which are closely associated with greater dystocia rates (Meijering, 1984). However, this explanation is likely more valid when breeds other than Jersey are bred with Holstein, such as Brown Swiss, Guernsey, and Ayrshire. Genetic diversity can lead to inconsistencies in the size and shape of crossbred calves, making births more difficult. For instance, studies have shown that Holstein calves are significantly more likely to experience dystocia compared with Jersey calves, and when these breeds are crossed, the variability in birth weight and size can exacerbate CD (Duarte-Ortuño et al., 1988). Additionally, Ferrell (1991) evaluated maternal and fetal influences on the development of gravid uterine tissues in Brahman and Charolais cows and showed that, although the maternal uterine environment influences fetal growth, sires from larger breeds crossed to relatively smaller breed dams will produce heavier fetuses growing in smaller carunculae. Thus, crossbreeding can potentially cause size and pelvic conformation mismatches, as observed, increasing the risk of dystocia. Nevertheless, selection for maternal genetics only for direct effects is not likely to generate any significant change in calving difficulty as a maternal trait (Balcerzak et al., 1989).

Last, there was an effect of CS ($P < 0.01$) on MY, where cows gestating males produced more than cows carrying female calves. Previous research has demonstrated that cows gestating female calves produce significantly more milk than those carrying male calves. This effect has been attributed to the different hormonal environments created by fetal sex during pregnancy, which influences milk production (Hinde et al., 2014). However, Hess et al. (2016) found that the increased milk production associated with gestating female calves was observed only in multiparous cows. This suggests that the relationship between fetal sex and milk production is more complex than previously indicated. Additionally, it should be noted that Hinde et al. (2014) did not include CD in their model. Our study clearly shows that there is an interaction between CD and other variables, such as CS. The observation of increased milk production for cows gestating male calves can be explained by the greater levels of androgens typically produced by male fetuses. These androgens can affect maternal endocrine function and stimulate mammary gland development. Yet, male fetuses are typically larger and grow faster than female fetuses, which requires more nutri-

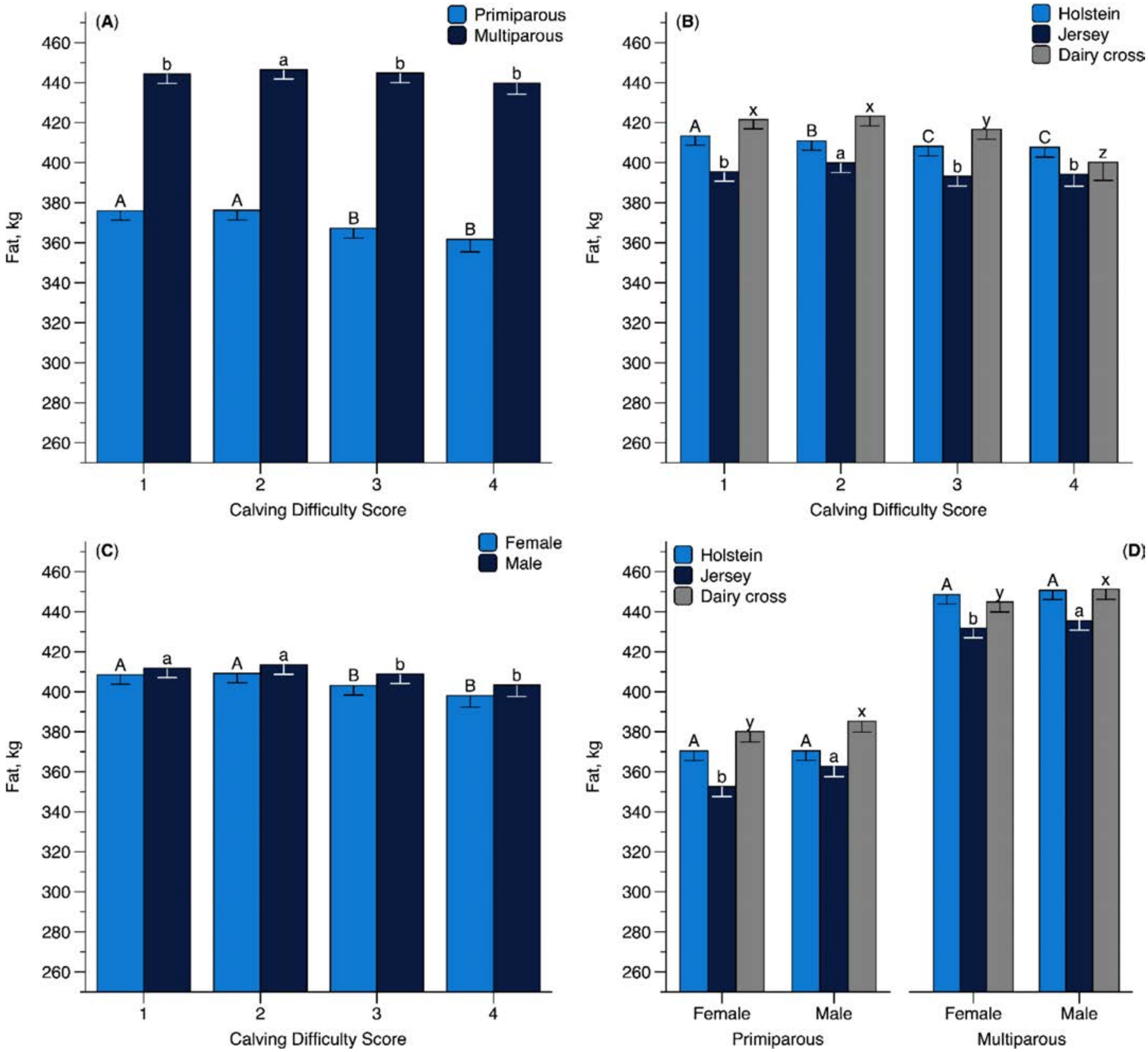

Figure 3. Effects of parity (primiparous and multiparous), breed, calf sex, and calving difficulty on best-predicted 305-day milk fat in US dairy herds. Bars represent mean ±SE. (A) Different uppercase letters (A, B) and lowercase letters (a, b) compare calving scores within lactation number (means with different letters are significantly different, $P < 0.05$). (B) Different uppercase letters (A–C), lowercase letters (a, b), and lowercase letters (x–z) compare calving scores within breed ($P < 0.05$). (C) Different uppercase letters (A, B) and lowercase letters (a, b) compare calving scores within sex ($P < 0.05$). (D) This panel represents the triple interaction, and letters compared breeds within lactation × sex ($P < 0.05$).

ents, and this increased nutritional demand can stimulate the mother's body to produce more milk (Hinde, 2007). Nonetheless, further research is needed on this topic, especially with cattle.

For milk fat, we did not observe any significant 4-way or 3-way interactions ($P > 0.05$). However, significant interactions were found between breed, CS, and parity with CD ($P < 0.05$), as presented in Figure 3. In primiparous cows, there was a decrease in milk fat from CD 2 to 3, with no further decrease observed at CD 4. Conversely, in multiparous cows, milk fat increased from CD 1 to 2, decreased from CD 2 to 3, and remained stable from CD 3 to 4. This increase in milk fat followed a similar trend as milk yield, likely influenced by the milk production patterns observed. It is possible that physical manipulation of the uterus during calving, particularly in cases of mild dystocia, may stimulate lactation. Although evidence supporting this is limited, interventions during difficult births, such as repositioning the calf or providing manual assistance, may indirectly affect lactation by influencing stress levels and overall postpartum recovery (Mota-Rojas et al., 2022; Szenci, 2022). Effective calving management, especially minimizing stress during interventions, is vital in promoting optimal lactation. Although direct stimulation of lactation through uterine manipulation is not well documented, ensuring smooth calving and proper postpartum care is essential for maintaining milk yield (Szenci, 2022).

Regarding breed, there was a decrease in milk fat from CD 1 to 3 and no further decrease in CD 4 for Holstein cows. In Jerseys, CD 2 had the greatest milk fat. In addition, in XD, there were no differences between CD 1 and 2 and a linear decrease from CD 2 to CD 4. Last, although there was a significant interaction between CS and CD ($P < 0.01$), the response was the same between males and females, where CD 1 and CD 2 did not differ and were greater than CD 3 and 4. As discussed before, it is noteworthy that dams carrying male calves produce more milk fat than those carrying females.

Explaining the link between CD and milk composition is not an easy task. This is more likely linked to energy intake or animal behavior than to a direct effect, where the stress and increased physiological demands on the cow can impair nutrient absorption and assimilation, leading to changes in milk composition. For example, the pain and stress from dystocia can affect the cow's ability to stand and move properly, often associated with increased standing bouts (Metz and Metz, 1987), reduced eating time and DMI (Proudfoot et al., 2009), and, consequently, decreased rumination. These factors can lead to metabolic disorders, affecting the metabolic status of a cow and nutrient availability to the mammary gland, thereby affecting milk composition (Bruckmaier and Gross, 2017). Increased cortisol levels during dystocia, or high CD scores, can inhibit the synthesis of prolactin and oxytocin, impairing milk ejection and let-down in fresh cows, which consequently leads to decreased milk yield (Huzzey et al., 2005). Furthermore, tissue trauma and inflammation during dystocia can increase cytokine levels, diverting metabolic energy away from milk production to tissue recovery (Murray et al., 2015). Dystocia is often linked to reduced DMI, which could lead to metabolic disorders such as ketosis and hypocalcemia and can further impair milk yield and alter composition (Goff, 2008). Hypocalcemia, in particular, reduces smooth muscle contractility, negatively affecting milk secretion (Reinhardt et al., 2011). Prolonged labor can also delay uterine involution, extending recovery time and further reducing milk production (Santos et al., 2004). Last, cows experiencing dystocia often exhibit a negative energy balance, leading to reduced milk fat and protein content (Overton and Waldron, 2004). Moreover, these cows are more susceptible to mastitis, which can elevate SCC, further compromising milk quality (Peeler et al., 1994). Thus, the hormonal imbalances and physiological challenges during dystocia can result in decreased milk yields and altered milk composition, underscoring the need to manage this condition to mitigate its long-term effects on dairy production.

For milk protein, we did not observe any significant 4-way or 3-way interactions with CD. However, milk protein levels were influenced by 3 significant 2-way interactions: (1) parity × CD, (2) breed × CD, and (3) breed × CS ($P < 0.05$), as shown in Figure 4. In primiparous cows, there was a linear decrease in milk protein content as CD increased from 2 to 4. In multiparous cows, there was an increase in milk protein from CD 1 to CD 2, followed by a linear decrease until CD 4, similar to the patterns observed for milk fat and MY. In Holsteins, milk protein levels decreased from CD 1 to CD 3, with no further decrease at CD 4. In contrast, Jerseys showed a decrease in milk protein from CD 2 to CD 3, with no additional decrease at CD 4. Crossbred cows exhibited the greatest milk protein levels at CD 2, followed by a pronounced decrease until CD 4, mirroring the trend observed for milk yield. The reasons behind the decrease in milk protein in greater CD levels are likely the same as discussed previously for milk fat.

When MY and milk composition were grouped as ECM, some changes were observed. There were no significant 4-way or 3-way interactions with CD ($P > 0.05$), and all interactions between CS and CD disappeared ($P > 0.05$), as observed in Figure 5. However, 2 significant 2-way interactions were identified: (1) parity × CD and (2) breed × CD ($P < 0.05$). In primiparous cows, ECM decreased from CD 2 to CD 3, with no further decrease beyond that point. In multiparous cows, ECM increased from CD 1 to CD 2 and then exhibited a linear decrease until CD 4. For Holstein cows, ECM dropped from CD 1 to CD 2, and no further significant changes were observed. In contrast, Jersey cows showed an increase in ECM from CD 1 to CD 2, followed by a significant decrease from CD 2 to CD 3, with no additional changes at CD 4. Last, in crossbred cows, ECM remained unchanged between CD 1 and CD 2 but then showed a substantial linear decrease from CD 2 to 4. These results highlight the complex interactions among CD, parity, and breed and their combined effects on milk production and composition.

Despite the significant results observed here, a bias is always present when evaluating CD because cows with greater scores of CD are more likely to be culled and tend not to finish their lactations (McGuirk et al., 2007). For that reason, the effect of CD on the observed variables, especially ECM (because it groups the effects of yield and components), may be greater than the ones we presented. Calving difficulty can lead to a range of health issues, such as decreased fertility, increased risk of lameness, and decreased milk yields, which collectively contribute to greater culling rates (Oltenacu et al., 1988). Cows that experience dystocia often have delayed resumption of ovarian activity and prolonged intervals to conception. These fertility issues increase the likelihood of culling because

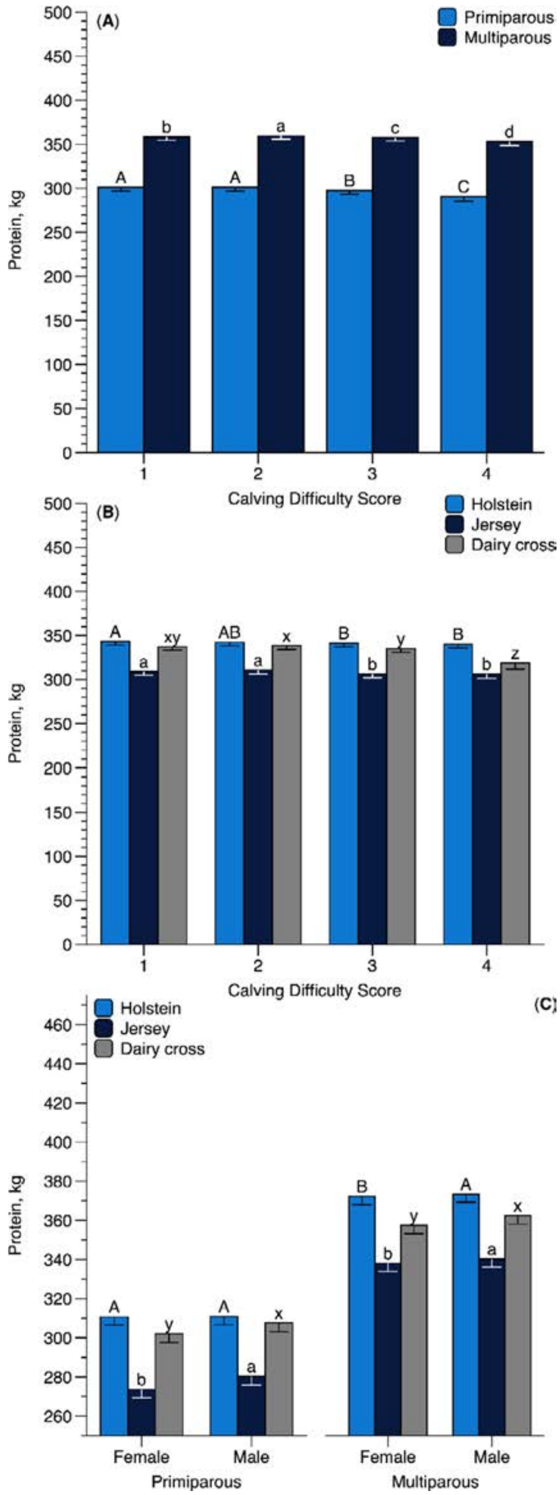

Figure 4. Effects of parity (primiparous and multiparous), breed, calf sex, and calving difficulty on best-predicted 305-day milk protein in US dairy herds. Bars represent mean ±SE. (A) Different uppercase letters (A–C) and lowercase letters (a–d) compare calving scores within lactation number (means with different letters are significantly different, $P < 0.05$). (B) Different uppercase letters (A, B), lowercase letters (a, b), and lowercase letters (x–z) compare calving scores within breed ($P < 0.05$). (C) Different uppercase letters (A, B), lowercase letters (a, b), and lowercase letters (x, y) compare sex within lactation number × breed ($P < 0.05$).

maintaining cows that do not conceive in a timely manner is economically unfeasible for dairy operations (Nasr et al., 2021). Dystocia can also lead to several health complications, including an increased risk of lameness and other postpartum disorders such as metritis and retained placenta. These conditions not only affect the immediate health of the cow but also affect long-term productivity and reproductive performance, leading to early culling (Malašauskienė et al., 2022). For that reason, the results shown herein should always be evaluated with care. Last, according to Borkowska and Januś (2009), early culling may prevent cows from reaching their production peak. Waiting to decide on culling until 80 to 100 DIM or at the lactation peak could improve decision making and help avoid high early culling rates in the herd.

No 4-way or 3-way interactions were observed for MLP ($P > 0.05$). Although parity and CS did affect MLP ($P < 0.01$), they did not interact with CD ($P = 0.16$). Breed was the only independent variable that interacted with CD ($P < 0.01$), as presented in Figure 6. This analysis demonstrates that some observed effects for variables such as MY, milk fat, milk protein, and ECM are influenced by culling decisions within the dairy herd. The decrease in all evaluated variables was relatively mild (<10%) when cows calved with CD 4. When comparing ECM and MLP, we observed that the differences between the greatest and least ECM were 1.1%, 1.6%, and 5.7% for Holstein, Jersey, and XD cows, respectively. In contrast, these differences were 1.3%, 4.6%, and 7.6% for the same breeds when MLP was evaluated. This indicates that although we may slightly underestimate the effect of CD on milk yield and composition, the bias introduced by early culling is minimal. This finding reinforces the validity of our data, providing significant value to the scientific community by ensuring that our conclusions are based on reliable and consistent data.

Another possibility is the confounding effect between calving BW or BCS and CD. Usually, there is a positive correlation between very low or very high BW or BCS and CD (Souissi and Bouraoui, 2020). To partially address this issue, we evaluated the effect of adding AFC as a covariate in the model in step 2, considering both linear and quadratic effects, to observe changes in the responses obtained in step 1. Interestingly, incorporating AFC into the model resulted in the disappearance of all interactions (Supplemental Material, see Notes), leaving only isolated effects. This pattern was consistent across all variables, showing greater production for Holstein cows compared with Jersey cows ($P < 0.01$), greater production for male calves compared with female calves ($P < 0.05$), and a quadratic effect of AFC ($P < 0.01$) on the evaluated response variables (Figure 7).

Our data suggest that animals calving too early (or possibly with too low BW) or too late (or too heavy BW) may have greater CD (or dystocia). Their pelvic size and overall physical maturity may be insufficient to easily deliver a calf, increasing the likelihood of dystocia (Norman

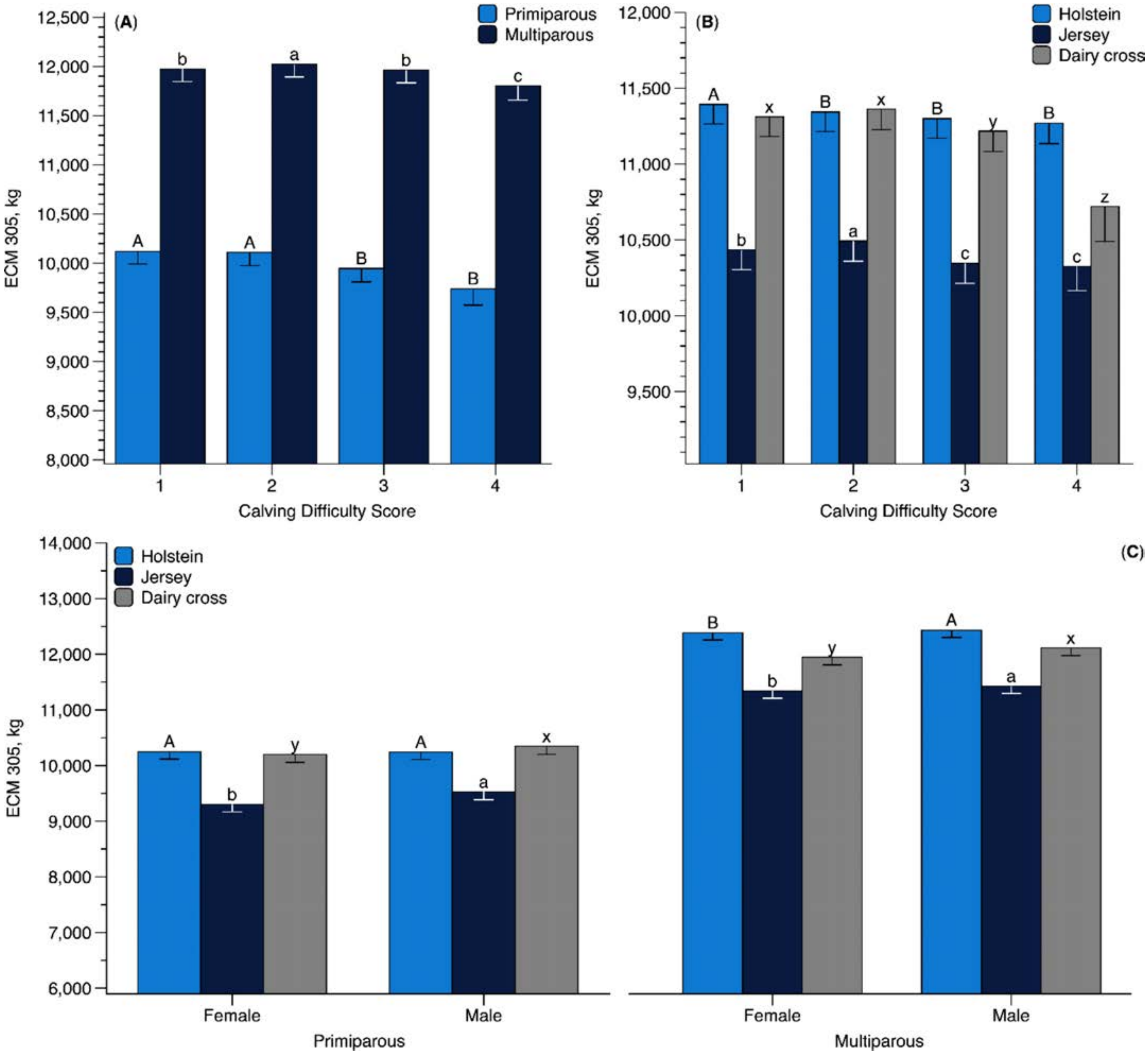

Figure 5. Effects of parity (primiparous and multiparous), breed, calf sex, and calving difficulty on best-predicted 305-day ECM in US dairy herds. Bars represent mean ±SE. (A) Different uppercase letters (A, B) and lowercase letters (a–c) compare calving scores within lactation number (means with different letters are significantly different, $P < 0.05$). (B) Different uppercase letters (A, B), lowercase letters (a–c), and lowercase letters (x–z) compare calving scores within breed ($P < 0.05$). (C) Different uppercase letters (A, B), lowercase letters (a, b), and lowercase letters (x, y) compare sex with breed × lactation number ($P < 0.05$).

et al., 2009). Another issue with early calving relates to mammary development. During prepuberty, puberty, and gestation, the mammary gland undergoes crucial changes, driven by growth hormone, progesterone, estrogen, and prolactin (Sinha and Tucker, 1969; Tucker, 1981). These changes include ductal elongation, side branching, and lobule-alveolar growth, all essential for optimal future milk production (Akers et al., 1981; Berry et al., 2001). In this context, we could infer that heifers bred too early miss critical estrous cycles, thus lacking the sufficient hormonal orchestration needed for full mammary development, which may explain why heifers calving at 27 to 28 mo perform better and have fewer events of dystocia.

Conversely, heifers that calve at an older age may have excessive BW and body fat in the pelvic area, contributing to dystocia. Heavier heifers are more prone to metabolic and physical stress during calving, which can complicate the birthing process. Overconditioned heifers also tend to have larger calves, further increasing the risk of dystocia (Xiong et al., 2023). Interestingly, the AFC that maximized milk performance and composition was around 27 to 28 mo, which is very different from the usual 22 to

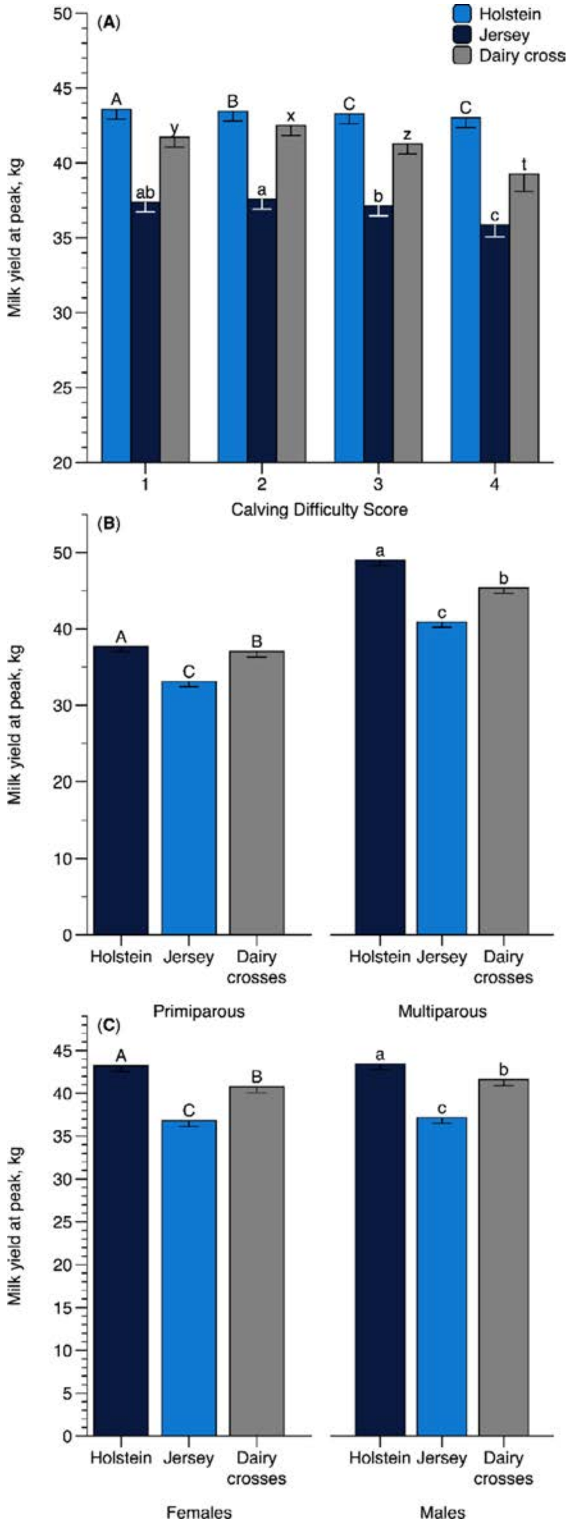

Figure 6. Effects of parity (primiparous and multiparous), breed, calf sex, and calving difficulty on milk yield at lactation peak in US dairy herds. Bars represent mean ±SE. (A) Different uppercase letters (A–C), lowercase letters (a–c), and lowercase letters (x–z) compare calving scores within breed (means with different letters are significantly different, $P < 0.05$). (B) Different uppercase letters (A–C) and lowercase letters (a–c) compare breeds within lactation number ($P < 0.05$). (C) Different uppercase letters (A–C) and lowercase letters (a–c) compare breeds within sex ($P < 0.05$).

24 mo of AFC frequently used in dairy farms across the United States (Hoffman, 1997). The costs associated with rearing dairy heifers, from weaning to calving, represent a significant portion of a farm's expenses. During this growth phase, heifers are unproductive and do not generate income for the producer. To mitigate these costs, dairy producers often accelerate the rearing phase to achieve earlier puberty and, consequently, earlier calving (Gabler et al., 2000; Overton and Dhuyvetter, 2020).

On another perspective in dairy herd management, a contentious topic has been whether excessive BW gain, particularly during the prepubertal growth period, adversely affects mammary gland development and subsequent milk production. Daniels et al. (2009) investigated the effects of 2 different growth rates, 650 and 950 g/d on Holstein heifers by assessing growth and conducting serial slaughter measurements. They found that the rate of gain itself had minimal effect on the histological development of the mammary gland. However, it is likely that an ADG exceeding 1 kg leads to internal fat accumulation in the birth canal, as suggested by Fortin et al. (1980), resulting in calving difficulties and metabolic issues during the first lactation. And, that highlights the importance of managing heifer BCS through proper nutrition and health management practices to minimize CD and improve overall herd productivity and longevity. Thus, proper management of BCS, especially during critical periods such as the heifer growing phase and around calving, is essential for maintaining cow health and optimizing performance.

To further understand the importance of CD in dairy farms, we evaluated CD as a response variable and evaluated the effects of AFC, CS, breed, and their interactions on CD in step 3. The only nonsignificant parameter was the interaction between AFC and breed ($P = 0.1025$; Supplemental Material, see Notes); thus, CD was affected by breed, CS, and AFC and several interactions ($P < 0.05$). By deconstructing the interactions, we found that CD was affected quadratically by AFC. The AFC that minimizes CD is 27 mo for Holstein, 25 mo for Jersey, and 28 mo for XD (Figure 8). However, this was only true for cows gestating male calves. For female calves, there was a minimal influence on CD, with only a slight linear effect observed when cows were carrying female calves. Although these results were statistically significant ($P < 0.01$), the curve was almost flat and has little biological consequence. Most of these results were previously discussed in this study, but the lack of effect of female calves on CD, regardless of breed, was unexpected. Although it is well known that female calves lead to easier calving events, the absence of a relationship between AFC and CD in cows carrying female calves warrants further investigation.

For our last step, we investigated the relationship between culling and CD, once they are closely related factors in dairy cattle management. Calving difficulty can lead to greater culling rates because cows experiencing challenging births are more likely to suffer from health complications, reduced fertility, and decreased milk production.

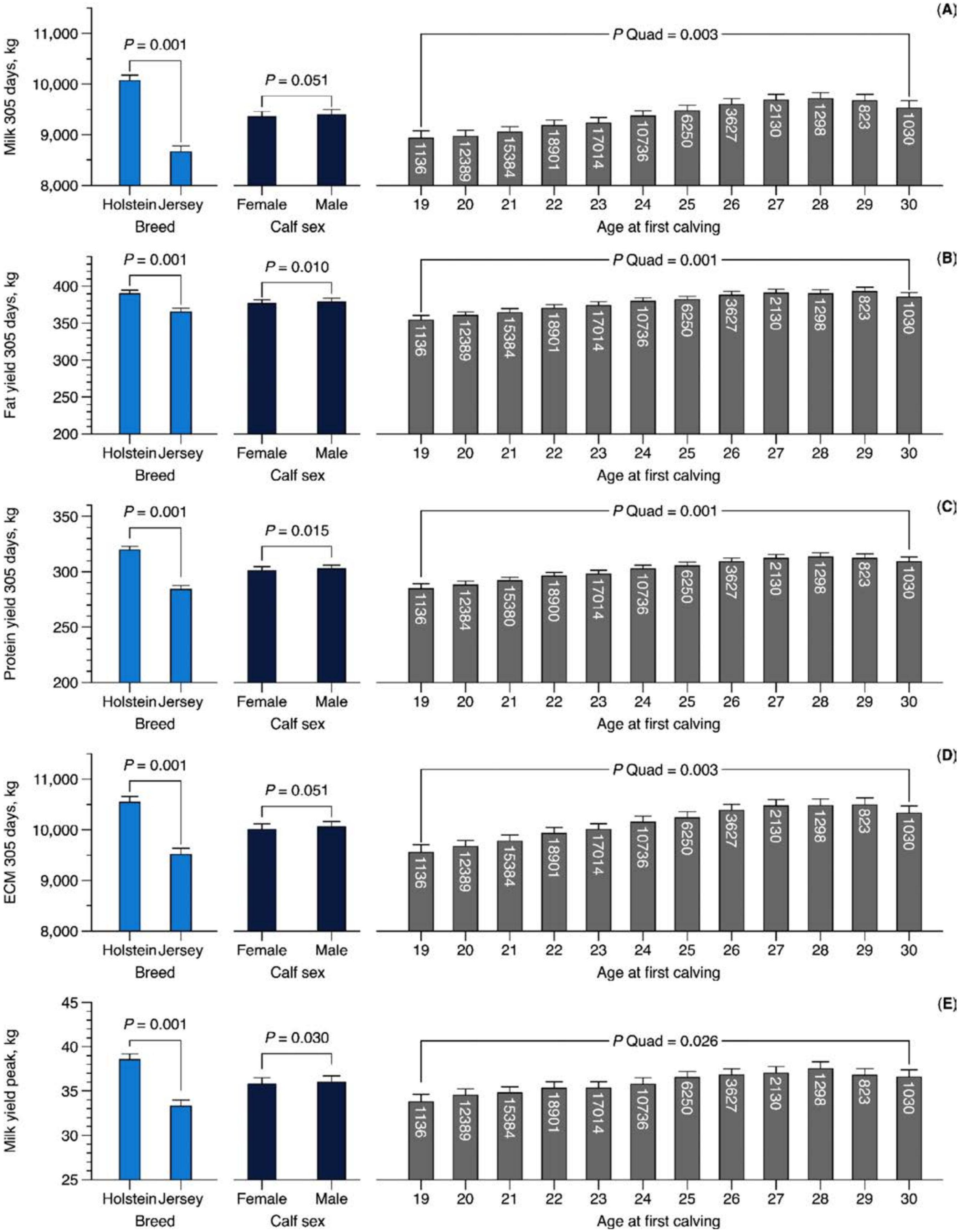

Figure 7. Effects of breed, calf sex, and calving difficulty on best-predicted 305-day milk, fat, and protein yields and milk yield at the lactation peak in primiparous cows in US dairy herds, using age at first calving (in months) as a covariate. Bars represent mean ±SE. A number in a gray bar is the number of replications for the LSM.

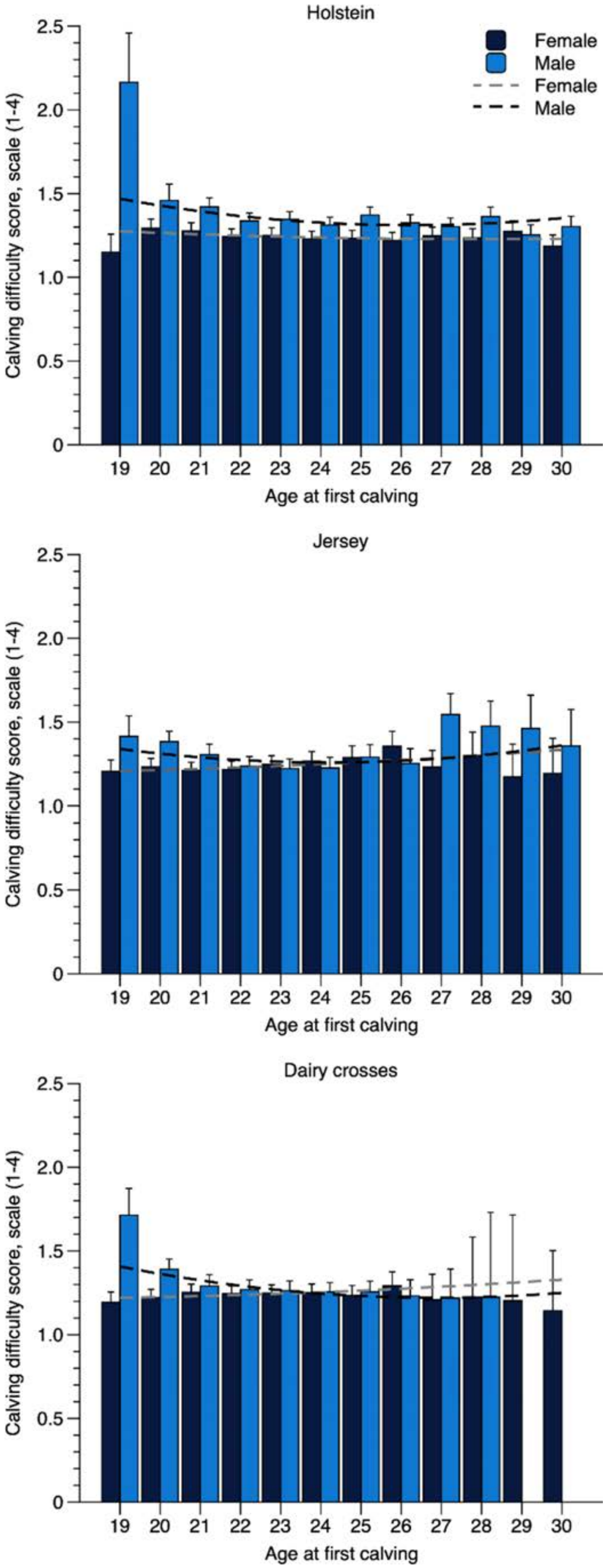

Figure 8. Effects of breed and calf sex on calving difficulty in US dairy herds. Bars represent mean ±SE.

These issues can negatively affect the overall productivity and profitability of the herd. In particular, cows that experience severe dystocia may require extensive veterinary care, which increases costs, and they may be less likely to conceive in future breeding cycles. Additionally, calving difficulties can result in greater calf mortality, further influencing decisions to cull the cow.

Thus, in step 4, we used logistic regression to examine the relationship between culling and CD. By varying the reference culling factor, we were able to compare the importance of different reasons for leaving the herd and their effect on CD (Supplemental Material, see Notes). When "dairy purpose" was used as the reference, we found that cows were more likely to have greater CD when other reasons for leaving the herd were detected (Figure 9). This indicates that high CD is more likely to lead cows to low production, reproductive issues, and so on, ultimately resulting in their culling. This also suggests that most of the dairies in our database rarely cull cows specifically for dairy purposes.

By isolating low production from dairy purposes in our analysis, we inferred that culling classified as a "dairy purpose" is likely linked to dairy trait types, such as leg and udder conformation. Culling is typically classified as voluntary or involuntary. Dairy type traits and low production are generally considered voluntary culling (when the producer chooses to sell a cow because it is more profitable to replace that cow with a different one), whereas reproductive issues, death, and sickness are considered involuntary culling because they are unavoidable (Fetrow et al., 2006).

In dairy farming, the goal is to be able to sort cows for culling voluntarily (Weigel et al., 2003). However, as shown in Figure 9, cows culled involuntarily are more likely to have greater CD than those culled voluntarily ($P < 0.01$). It is interesting to note that reproduction issues and sickness affected CD at almost the same rate (0.96; $P = 0.07$). This indicates that a high CD will lead to a culling event at a similar rate for cows experiencing reproductive problems or sickness. Involuntary culling is strongly linked with management quality, whereas voluntary culling is influenced by both management and cow genetics. Therefore, farms continuously strive to improve management practices to reduce involuntary culling and increase the ability to cull cows voluntarily (Hadley et al., 2006).

Cows with a history of dystocia are at a greater risk of being culled due to direct effects, such as severe injury, and indirect effects, such as reduced fertility and increased susceptibility to diseases. Difficult calving is associated with increased risks of postpartum diseases (e.g., metritis, retained placenta, and ketosis), which can further impair reproductive performance (Mee, 2008). The combined effects of CD can have long-term effects, often resulting in reduced milk yield, impaired reproduction, extended calving intervals, a greater incidence of diseases, and poorer overall health and welfare, significantly increasing the likelihood of early culling (Sewalem et al., 2008; De Vries et

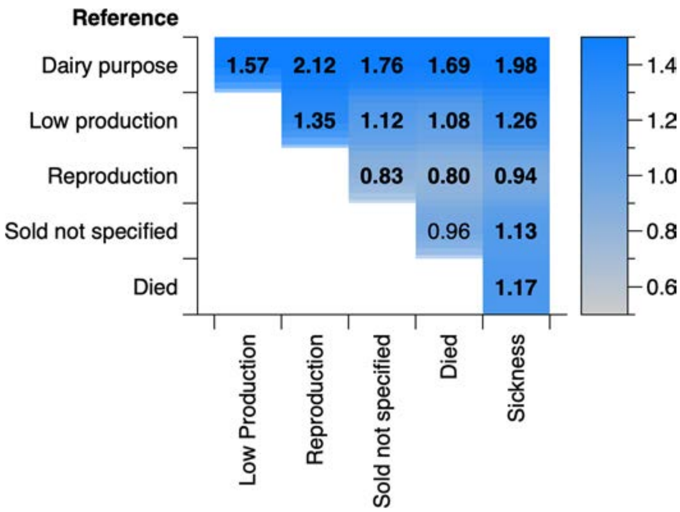

Figure 9. Odds ratios of caving difficulty according to reasons for leaving the herd, with different reasons as reference in the analysis. Sickness = lameness, mastitis, and udder and lactation problems. Values in bold were significant (*P* < 0.01).

al., 2010; Hertl et al., 2010). In this study, we evaluated several factors, including breed, CS, and parity, that could affect CD and the connection between CD and culling. Improving our understanding of these factors can help dairy farms refine their management practices and make more informed culling decisions. Overall, our study contributes to a broader understanding of the relationships among culling decisions, dairy cow management, and CD, reinforcing the need for ongoing research and improvement in farm practices to optimize animal welfare and production efficiency.

APPLICATIONS

A comprehensive understanding of the risk factors influencing CD in dairy cattle—such as breed, calf sex, and the number of lactations—can help farmers make informed decisions and manage potential calving issues more effectively. This knowledge enables better breeding and management strategies, improving overall herd health and productivity. Calving difficulty negatively affects milk production, ECM, and fat and protein yields, highlighting the need for careful monitoring of cows with difficult births. Although the effect on production traits is less significant than expected, maintaining optimal milk production remains crucial for herd welfare and dairy system profitability. Additionally, the significant effect of AFC on CD in younger (less than 23 mo) and older animals (over 26 mo) suggests that the ideal timing of first calving can reduce calving complications and improve herd longevity and productivity. The increased likelihood of involuntary culling among animals with greater CD underscores the importance of proactive health and management practices. By identifying and addressing the factors contributing to CD, farmers can reduce involuntary culling rates, thereby improving herd sustainability and profitability.

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NOTES

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Nonstandard Abbreviations Used: AFC = age at first calving; CD = calving difficulty; CS = calf sex; CY = calving year; MLP = milk yield at lactation peak; MY = milk yield; XD = dairy cross breeds.

ORCIDS: M. I. Marcondes https://orcid.org/0000-0003-4843-2809

J. C. C. Chagas https://orcid.org/0000-0001-6982-425X

A. F. Kertz https://orcid.org/0000-0003-3794-0146