J. Dairy Sci. 104:11738–11746
https://doi.org/10.3168/jds.2021-20354

Growth, milk production, reproductive performance, and stayability of dairy heifers born from 2-year-old or mixed-age dams

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ABSTRACT

Keeping replacement heifers that were the progeny of primiparous cows mated by artificial insemination enhances rates of genetic gain. Previous research has shown that heifers that were the progeny of primiparous cows were lighter at birth and grew at a slower rate to first calving compared with heifers born to multiparous dams. Furthermore, heifers that were heavier before first calving produced more milk than did lighter heifers. This study aimed to determine whether there were body weight, milk production, or reproductive disadvantages for heifers born from primiparous compared with multiparous dams. Data comprised body weight records from 189,936 New Zealand dairy heifers. Dams were allocated to 4 groups according to their age: 2 yr old (n = 13,717), 3 yr old (n = 39,258), 4 to 8 yr old (n = 120,859), and 9 yr or older (n = 16,102). Heifers that were the progeny of 2-yr-old dams were lighter from 3 to 21 mo of age than heifers that were the progeny of 3-yr-old and 4- to 8-yr-old dams. The progeny of 2- and 3-yr-old dams produced similar milk solids yields (± standard error of the mean) during their first lactation (304.9 ± 1.6 and 304.1 ± 1.5 kg, respectively), but more than that of 4- to 8-yr-old dams (302.4 ± 1.5). Furthermore, the progeny of 2-yr-old dams had similar stayabilities to first, second, and third calving to that of the progeny of 4- to 8-yr-old and ≥9-yr-old dams. Reproductive performance, as measured by calving and recalving rates was similar in first-calving heifers of all age-of-dam classes. Additionally, second and third calving rates were similar for the progeny of 2- and 3-yr-old dams. Interestingly, the progeny of dams ≥9 yr old had the lowest milk solids production in first (297.8 ± 1.6 kg), second (341.6 ± 1.8 kg), and third lactations (393.2 ± 2.4 kg). Based on the results of this study, keeping replacements from dams aged 9 yr and over could not be recommended. Furthermore, heifers born to 2-yr-old dams were lighter but produced more milk than heifers from older dams, in addition to having superior genetic merit.
Key words: dam, growth, milk, heifer, survival

INTRODUCTION

In New Zealand's seasonal calving system, it is common practice for 15-mo-old dairy heifers to be naturally mated with Jersey bulls (Burke et al., 2007), often of unknown genetic merit. Both the male and female resulting progeny are usually slaughtered between 4 and 10 d of age due to being the progeny of natural mating bulls. Approximately one-third of all calves that are slaughtered before 10 d of age in New Zealand are the progeny of first-calving (2-yr-old) heifers (Livestock Improvement Corp. internal database, Hamilton, New Zealand). There is an increased awareness of, and consumer resistance to, the slaughter of these young calves (Fisher et al., 2017). Approximately 20% of heifers are artificially inseminated each year (Livestock Improvement Corporation and DairyNZ, 2018), and the resulting heifer calves are usually retained as replacements rather than slaughtered; therefore, increased adoption of artificial insemination instead of natural matings could reduce the number of unwanted calves produced by heifers. In addition, the rate of genetic gain in the dairy industry can be improved by using semen of high-genetic-merit bulls in 15-mo-old heifers and by keeping replacement heifers from these younger dams (Johnson et al., 2018). However, heifers born to primiparous dams were lighter at birth (Hickson et al., 2015), had slower growth rates (Place et al., 1998), and tended to be lighter at calving (Heinrichs et al., 2005) compared with heifers born to multiparous dams.

Previous research has demonstrated that heifers that were lighter before first calving produced less milk in first (Carson et al., 2002) and subsequent lactations (van der Waaij et al., 1997; McNaughton and Lopdell,

Received February 23, 2021.
Accepted July 12, 2021.
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2013; Handcock et al., 2019b) compared with heifers that were heavier. Furthermore, there are few reports that describe milk production of the progeny of dams differing in age; one such report was of dual-purpose Simmental cows in Austria (Fuerst-Waltl et al., 2004). In that population, the progeny of younger dams produced greater milk yields than did those from older dams (Fuerst-Waltl et al., 2004); however, to the authors knowledge, there is no such study on cattle bred for dairy purposes alone.

Additionally, there is little information available on the reproductive success or stayability of the progeny of dams differing in age. Stayability is defined as the probability of an animal surviving to a specific age given that they had the opportunity to reach that age (Hudson and Van Vleck, 1981).

To determine if replacement heifers should be generated from primiparous heifers, it is necessary to identify if there are BW disadvantages between 3 and 21 mo of age for the progeny of 2-yr-old dams, and whether these heifers produce similar milk yields or have comparable reproductive performance to those born to older dams. The aim of this study was to quantify heifer BW, milk production and reproductive performance of the progeny of primiparous or multiparous dams.

MATERIALS AND METHODS

Initial Data Set

Body weight records were extracted from the Livestock Improvement Corporation (**LIC**) internal national dairy database from 189,936 spring-born New Zealand dairy heifers born between 2006 and 2013 spring-calving dairy seasons (Handcock et al., 2019a). Heifers were included in the data set if they had at least 2 records of BW between birth and 12 mo of age and at least 2 records of BW between 13 mo of age and first calving at 2 yr of age (Handcock et al., 2019a). Random regression of a fourth-order Legendre polynomial was used to generate growth curves for each heifer in ASReml (Gilmour et al., 2015), as described by Handcock et al. (2019a). Using the regression coefficients from the growth curves, BW were predicted for each heifer between 3 and 21 mo of age in SAS version 9.4 (SAS Institute Inc.).

Only heifers with known dam and sire, and with ≤12.5% of breeds other than Holstein-Friesian (**F**) or Jersey (**J**) in their breed composition were included in the data set. Breeds other (**O**) than F and J included Ayrshire, Brown Swiss, Milking Shorthorn, Guernsey, or unknown. Using recorded pedigree, and sire and dam breed proportions, individual animals' breed proportions were determined, and were used to calculate the coefficient of specific heterosis between F and J, F and O, and J and O using the following formula:

$$h_{ij} = \alpha_{si}\alpha_{dj} + \alpha_{sj}\alpha_{di},$$

where h_{ij} is the coefficient of expected heterosis between breeds i and j in the progeny; α_{si} and α_{sj} are proportions of breeds i and j in the sire, respectively; and α_{di} and α_{dj} are proportions of breed i and j in the dam, respectively (Dickerson, 1973).

Heifers were allocated to 4 groups according to their dam's age when the heifer was born: 2 yr old (n = 13,717), 3 yr old (n = 39,258), 4 to 8 yr old (n = 120,859) and 9 yr old or older (n = 16,102). In New Zealand, it is highly unusual for a heifer to have her first calf at 3 yr old, so it can be assumed that all 3-yr-old dams were in their second lactation. In addition, nonpregnant cows in New Zealand are routinely culled, with less than 5% of 2-yr-old first-lactation cows being dried-off and re-entering the milking herd as 4-yr-old second-lactation cows and retained for subsequent lactations (Gardner et al., 2020). This means that age is almost synonymous with lactation number, and those that deviate from the norm would be unlikely to do so by more than one lactation [i.e., 5-yr-old cows would normally be fourth lactation, and a small proportion would be third lactation (less than 4%; Gardner et al., 2020)]. For this reason, it is appropriate to consider the effect of age without also considering the effect of lactation number for this analysis.

Stayability Data Set

Stayability was measured to first calving as a 2-yr-old (**C2yr**), second calving as a 3-yr-old (**C3yr**), and third calving as a 4-yr-old (**C4yr**) as described by Handcock et al. (2020). Calving dates of the 189,936 heifers were extracted from the LIC internal national dairy database for the "spring-calving" seasons between June 2008 and December 2017.

Heifers that calved between June and December at approximately 2 yr of age were coded "1" for C2yr and those that did not were considered unsuccessful and coded "0" for C2yr, C3yr, and C4yr. Of the heifers that were successful for C2yr, those that had their second parturition in the spring-calving period at 3 yr of age were considered successful for C3yr, those that did not were considered unsuccessful for C3yr and C4yr. Finally, of the heifers that were successful for C3yr, those that were 4 yr of age at their third calving were considered successful for C4yr, and heifers that did not meet this criterion were considered unsuccessful for C4yr.

Marginal stayability was measured as follows: given an animal's presence at a particular calving (n), what was the probability of being present at the subsequent calving (n + 1). For example, marginal stayability to second calving as a 3-yr-old was measured as proportion that calved as a 3-yr-old, provided they calved as a 2-yr-old [P(C3yr|C2yr)], and likewise, for the proportion that calved as a 4-yr-old [P(C4yo|C3yo)].

Milk Production Data Set

Milk production records of the 175,142 heifers that calved for the first time as 2-yr-olds were extracted from the LIC internal national dairy database as described by Handcock et al. (2019b). Heifers with a lactation length of less than 80 d were excluded; this percentage of excluded records were similar across the 4 age-of-dam categories. Additionally, records outside of the following limits were also excluded: 30 to 300 kg of milk protein, 40 to 400 kg of milk fat, and 800 to 8,000 L of milk yield (Gardner et al., 2020). Lactations that were greater than 305 d were truncated at 305 d to remove any heifers that were milked for extended lactations, atypical of the New Zealand system. Heifers born after the 2012–2013 spring-calving dairy season (n = 50,584) were not considered for the third-lactation data set as, at the time of data extraction (December 2015), they were not old enough to have had 3 full lactations. This resulted in 140,113 heifers with suitable first-lactation records, 108,876 heifers with suitable second-lactation records, and 51,449 heifers with suitable third-lactation records (Handcock et al., 2019b).

A data set was created to examine the effect of age of dam on milk production accumulated over the first 3 lactations (3-parity production); provided the heifer was old enough to complete 3 lactations. Three-parity production was calculated as the sum of the first 3 lactations milk, fat, or protein yields (Handcock et al., 2019b). To avoid biases to the data due to animals not surviving to the end of their third lactation, animals that failed to complete all 3 lactations remained in the data set (Handcock et al., 2019b, 2020). Three-parity production was equivalent to the heifer's first-lactation production if she did not have a recorded second calving. Likewise, 3-parity production was equivalent to the sum of the heifer's first- and second-lactation production if she did not have a recorded third calving. After these data edits, there were 67,833 heifers remaining in the data set (Handcock et al., 2019b).

The milk production traits studied were; milk solids (sum of milk fat and milk protein), and ECM yield. The ECM was calculated using the equation below derived from Tyrrell and Reid (1965) by Beever and Doyle (2007):

$$\text{ECM (kg)} = \text{milk yield} \times (383 \times \text{fat percentage} + 242 \times \text{protein percentage} + 783.2)/3{,}140.$$

Calving and Recalving Rate Data Set

The proportion of animals that calved no more than 21 d after the fixed calendar date of planned start of calving (**PSC**) provided they calved that year was defined as calving rate (**C21**), and the proportion of animals that calved no more than 21 d after PSC provided they calved the year prior was defined as recalving rate (**RC21**).

Planned start of mating (**PSM**) and PSC dates for each herd-year combination were extracted from the LIC internal national dairy database and joined with the stayability data set as described by Handcock et al., 2020. The PSM and PSC dates were matched with the individual heifer records for heifers that had a first calving (C2yr; n = 175,142), second calving (C3yr; n = 143,696), and third calving (C4yr; n = 116,234) as 3 separate data sets. Heifers from herds with no PSC date for a herd-year were removed from the data sets. Based on the criteria used by Brownlie et al. (2014), the interval from PSC to calving was calculated for each heifer, and heifers that calved between 47 d before PSC and 142 d after PSC for each year were selected for the analysis of C21, heifers outside these criteria for each calving were removed from the data set for that calving. A heifer was coded "1" for C21 if she calved no more than 21 d after PSC and "0" if she calved later than 21 d.

To create the data set for RC21, heifers that did not have a recorded first calving as a 2yr in the stayability data set (n = 14,794) but were located in herds with PSC information (n = 13,161) were coded "0" for RC21_2yr and were added to the C21_2yr data set. Likewise, heifers that did not have a recorded second calving as a 3yr (n = 31,446) but were located in herds with PSC information (n = 28,868) were coded "0" for RC21_3yr and added to the C21_3yr data set. Finally, heifers that did not have a recorded third calving as a 4yr (n = 27,462) but were located in herds with PSC information (n = 24,529) were coded "0" for RC21_4yr and were merged with the C21_4yr data set.

Genetic Merit Subset

We expected that the progeny of 2-yr-old dams would have superior genetic merit to the progeny of older dams, therefore, a subset of data was extracted to compare genetic merit. The index used to rank cattle in New Zealand is Breeding Worth (**BrW**), which measures the expected ability of cattle to breed replacements to meet the national breeding objective, which is to breed dairy cows that are able to efficiently convert feed into profit (Johnson et al., 2018). The BrW index is made up of the combination of breeding values (**BV**; genetic merit for individual traits) and economic values (per dollar unit increase) of each trait to a New Zealand dairy farmer (Johnson et al., 2018).

Heifers born in 2011 (n = 24,281) were selected from each data set above and merged with their BrW and BV for protein (**Prot**), milk volume (**Milk**), SCS, fertility (**Fert**), residual survival (**Resid Surv**), BW from the May 31, 2013, animal evaluation run, extracted from the LIC internal national dairy database. The May 2013 BV were selected as these were the closest estimates of genetic merit without the heifers' own milk production or reproductive performance (variables of interest in this study) informing the estimation of the BV. In addition, only one year group could be compared, as BV between different animal evaluation runs are not comparable.

Statistical Analysis

All data were analyzed using SAS version 9.4 (SAS Institute Inc.). The least squares means of genetic merit were obtained using a generalized linear model that included the fixed effect of age of dam group. The least squares means of BW between 3 and 21 mo of age predicted from the Legendre polynomial were obtained using linear mixed models that included the fixed effects of age of dam, birth year, and the random effect of herd. Deviation from median date of birth (within herd-year), proportion of F, proportion of O, heterosis F×J, heterosis F×O, and heterosis J×O were fitted as covariates.

Least squares means of stayability, calving rate, and recalving rate for age of dam were obtained using mixed models based on a binomial distribution and using a logit-transformation. The models included age of dam as a fixed effect, deviation from median date of birth (within herd-year), proportion of F, proportion of O, heterosis F×J, heterosis F×O, and heterosis J×O were fitted as covariates and herd-year as a random effect. Herd-year was defined as the herd and year at which the heifer started her first lactation. For second and third calving and recalving rates, the deviation from median date of calving (within herd-year) the year prior was added to the models.

The least squares means of milk production were obtained using linear mixed models that included the fixed effects of age of dam, and the random effect of herd-year. Deviation from median date of first calving (within herd-year), proportion of F, proportion of O, heterosis F×J, heterosis F×O and heterosis J×O were fitted as covariates.

RESULTS

The progeny of 4- to 8-yr-old dams made up 63.6% of the population studied. A further 20.7% were the progeny of 3-yr-old dams, 7.2% of 2-yr-old dams, and 8.5% of dams ≥9 yr old. The progeny of 2-yr-old dams had higher proportions of J and heterosis F×J, compared with the progeny of dams older than 2 yr old (Table 1). The subset of 2011-born heifers were comparable to the base population studied; there were similar proportions of heifers born from dams 2, 3, 4 to 8, and ≥9 yr old (7.4, 21.0, 62.7, and 8.9%, respectively; Table 1) as in the base population.

Based on genetic merit before first calving, heifers that were the progeny of 2- and 3-yr-old dams had the highest BrW ($P < 0.001$), followed by the progeny of 4- to 8-yr-old dams, and the progeny of dams ≥9 yr old had the lowest BrW ($P < 0.001$; Table 1). Fat and protein BV were greatest ($P < 0.001$) for heifers that were the progeny of 3-yr-old dams, and milk volume and BW BV were lowest ($P < 0.001$) for the progeny of 2-yr-old dams (Table 1). Fat BV was similar for the progeny of 2- and 9-yr-old dams ($P > 0.05$) and less than that of dams 4 to 8 yr old ($P < 0.001$; Table 1).

Body Weight

Due to the differences in breed proportions of progeny born to 2-yr-old versus older dams, BW was corrected for all breed and heterosis effects. Despite this, throughout the heifer-rearing phase (3 to 21 mo of age), the progeny of 2-yr-old dams were significantly lighter than the progeny of mixed-age dams (Table 2). Heifers from dams aged 4 to 8 yr were the heaviest ($P < 0.05$) at all ages studied (Table 2).

Stayability

Heifers that were the progeny of 2-yr-old dams had similar stayabilities to first, second, and third calving to progeny of dams 4 to 8 yr old and ≥9 yr old (Table 3). Stayability to first calving was similar for the progeny of 2- and 3-yr-old dams (92.9% and 93.3%, respectively; Table 3); however, stayability to second and third calving was superior ($P < 0.05$) for the progeny of 3-yr-old dams compared with the progeny of 2-yr-old dams (Table 3). There were no differences among

Table 1. Proportions (mean ± SEM) of Holstein-Friesian (F), Jersey (J), breeds other (O) than F or J, and heterosis (Het F×J) of 189,936 heifers and genetic merit[1] of a subset of dairy heifers born in 2011 to 2012 that were the progeny of 2-yr-old, 3-yr-old, 4- to 8-yr-old, or 9-yr-old and older dams

	Age of dam			
Heifer[2]	2 yr	3 yr	4–8 yr	≥9 yr
All heifers (n)	13,717	39,258	120,859	16,102
F Proportion	0.439 ± 0.002	0.635 ± 0.001	0.642 ± 0.001	0.636 ± 0.002
J Proportion	0.546 ± 0.002	0.352 ± 0.001	0.347 ± 0.001	0.355 ± 0.002
O Proportion	0.015 ± 0.001	0.013 ± 0.000	0.011 ± 0.000	0.009 ± 0.001
Het F×J	0.503 ± 0.002	0.387 ± 0.001	0.403 ± 0.001	0.415 ± 0.002
2011–2012-born heifers (n)	1,766	5,119	15,273	2,123
F Proportion	0.402 ± 0.006	0.616 ± 0.004	0.620 ± 0.002	0.602 ± 0.006
J Proportion	0.583 ± 0.006	0.373 ± 0.004	0.370 ± 0.002	0.389 ± 0.006
O Proportion	0.015 ± 0.001	0.012 ± 0.000	0.010 ± 0.000	0.010 ± 0.001
Het F×J	0.487 ± 0.006	0.400 ± 0.004	0.415 ± 0.002	0.433 ± 0.006
BrW ($)	135.47^{c} ± 0.91	136.35^{c} ± 0.54	128.17^{b} ± 0.31	113.18^{a} ± 0.83
Fat BV (kg)	13.41^{a} ± 0.16	16.24^{c} ± 0.10	15.28^{b} ± 0.06	13.72^{a} ± 0.15
Prot BV (kg)	9.06^{a} ± 0.20	14.33^{d} ± 0.12	13.59^{c} ± 0.07	10.88^{b} ± 0.19
Milk BV (L)	11.92^{a} ± 8.68	247.77^{c} ± 5.10	243.49^{c} ± 2.95	187.03^{b} ± 7.92
SCS BV (unit)	-0.018^{bc} ± 0.004	-0.024^{b} ± 0.002	-0.017^{c} ± 0.001	-0.037^{a} ± 0.004
Fert BV (%)	1.61^{a} ± 0.04	1.68^{a} ± 0.02	1.75^{b} ± 0.01	1.64^{a} ± 0.03
Resid Surv BV (d)	6.04^{d} ± 1.72	-7.36^{b} ± 1.01	-13.92^{a} ± 0.58	-2.09^{c} ± 1.56
BW BV (kg)	-13.79^{a} ± 0.58	3.96^{c} ± 0.34	3.81^{c} ± 0.20	0.94^{b} ± 0.53

[a–d]Values with differing superscripts within a row indicate significant differences at $P < 0.05$.

[1]Estimates of genetic merit were from the May 2013 Animal Evaluation run, before the heifers' first calving.

[2]BrW = breeding worth, BV = breeding value, Prot = protein, Milk = milk volume, Fert = fertility, Resid Surv = residual survival.

any age-of-dam categories for marginal stayability from first to second or second to third calving (Table 3).

Calving and Recalving Rate

There were no differences among any age-of-dam categories for first calving 21-d calving rate or 21-d recalving rate (Table 3). The progeny of 2-yr-old dams had lower second-calving 21-d calving rates (61.0%) compared with the progeny of dams 4 to 8 yr old (62.3%) but were not different to that of the progeny of dams 3 or ≥9 yr old (61.8% and 62.2%, respectively; Table 3). Likewise, the progeny of dams 3, 4 to 8, and ≥9 yr old had similar second-calving 21-d recalving rates to each other (Table 3). The progeny of 2-yr-old dams had lower ($P < 0.05$) second-calving 21-d recalving rates (49.4%) compared with the progeny of dams 4 to 8 yr old (50.7%) and ≥9 yr old (50.9%) but were not different to that of the progeny of 3-yr-old dams (50.5%: Table 3).

By third calving, the progeny of 2-yr-old dams had lower ($P < 0.05$) 21-d calving rates (57.2%) compared with the progeny of dams 4 to 8 yr old (58.8%) and ≥9 yr old (59.7%) but had similar 21-d calving rates to that of the progeny of 3-yr-old dams (58.3%; Table 3). Furthermore, the progeny of dams ≥9 yr old had the highest ($P < 0.05$; 48.3%) 21-d recalving rate for third calving, the progeny of dams 3 yr old or 4 to 8 yr old had similar third calving 21-d recalving rates to each other (46.9 and 47.1%, respectively) but were better

Table 2. Predicted BW (kg; least squares means ± SEM) between 3 and 21 mo of age of dairy heifers that were the progeny of 2-yr-old, 3-yr-old, 4- to 8-yr-old, or 9-yr-old and older dams

	Age of dam			
Age (mo)	2 yr	3 yr	4–8 yr	≥9 yr
3	89.0^{a} ± 0.3	90.3^{b} ± 0.3	91.0^{d} ± 0.3	90.5^{c} ± 0.3
6	149.9^{a} ± 0.5	151.4^{b} ± 0.5	152.1^{c} ± 0.5	151.3^{b} ± 0.5
9	186.6^{a} ± 0.6	187.5^{c} ± 0.6	188.1^{d} ± 0.6	187.1^{b} ± 0.6
12	230.3^{a} ± 0.7	231.1^{b} ± 0.6	231.8^{c} ± 0.6	230.4^{a} ± 0.7
15	291.6^{a} ± 0.7	293.2^{c} ± 0.7	294.1^{d} ± 0.7	292.4^{b} ± 0.7
18	362.2^{a} ± 0.8	365.1^{c} ± 0.7	366.3^{d} ± 0.7	364.3^{b} ± 0.7
21	411.6^{a} ± 0.7	415.0^{c} ± 0.7	415.9^{d} ± 0.7	414.2^{b} ± 0.7

[a–d]Predicted BW with differing superscripts within a row are significantly different ($P < 0.05$).

Table 3. Least squares means ± SEM for stayability, marginal stayability, calving rate, and recalving rate in first, second, and third calving dairy heifers that were the progeny of 2-yr-old, 3-yr-old, 4- to 8-yr-old, or 9-yr-old and older dams

	Age of dam			
Item[1]	2 yr	3 yr	4–8 yr	≥9 yr
Stayability (%)				
C2yr	$92.9^{ab} \pm 0.3$	$93.3^{b} \pm 0.2$	$93.1^{b} \pm 0.1$	$92.4^{a} \pm 0.2$
C3yr	$75.5^{a} \pm 0.5$	$76.5^{b} \pm 0.3$	$75.9^{a} \pm 0.2$	$75.8^{ab} \pm 0.4$
C4yr	$60.7^{a} \pm 0.5$	$61.9^{b} \pm 0.3$	$61.3^{ab} \pm 0.3$	$61.6^{ab} \pm 0.5$
Marginal stayability (%)				
C3yr|C2yr	82.1 ± 0.4	82.9 ± 0.2	82.5 ± 0.2	82.9 ± 0.3
C4yr|C3yr	81.3 ± 0.5	81.9 ± 0.3	81.8 ± 0.2	82.2 ± 0.4
Calving rate (21 d; %)				
C21_2yr	80.2 ± 0.5	81.0 ± 0.3	80.8 ± 0.2	80.9 ± 0.4
C21_3yr	$61.0^{a} \pm 0.6$	$61.8^{ab} \pm 0.4$	$62.3^{b} \pm 0.3$	$62.2^{ab} \pm 0.5$
C21_4yr	$57.2^{a} \pm 0.7$	$58.3^{ab} \pm 0.4$	$58.8^{bc} \pm 0.3$	$59.7^{c} \pm 0.6$
Recalving rate (21 d; %)				
RC21_2yr	74.0 ± 0.5	74.9 ± 0.3	74.5 ± 0.3	74.1 ± 0.4
RC21_3yr	$49.4^{a} \pm 0.6$	$50.5^{ab} \pm 0.4$	$50.7^{b} \pm 0.3$	$50.9^{b} \pm 0.5$
RC21_4yr	$45.4^{a} \pm 0.7$	$46.9^{b} \pm 0.4$	$47.1^{b} \pm 0.3$	$48.3^{c} \pm 0.6$

[a–c]Values with differing superscripts within a row indicate significant differences at $P < 0.05$.

[1]Stayability was measured as the proportion that had a first calving as a 2-yr-old (C2yr), second calving as a 3-yr-old (C3yr) and third calving as a 4-yr-old (C4yr); marginal stayability was the proportion that C3yr given that they C2yr (C3yr|C2yr) and the proportion that C4yr given that they C3yr (C4yr|C3yr); calving rate was the proportion of cows that calved within 21 d of planned start of calving (PSC) each year, and recalving rate was the proportion of cows that calved within 21 d of PSC provided they calved the year prior. C21 = calving rate at 21 d; RC21 = recalving rate at 21 d.

($P < 0.05$) than that of the progeny of 2-yr-old dams (45.4%).

Milk Production

Heifers that were the progeny of 2- and 3-yr-old dams produced similar quantities of milk solids in first lactation (304.9 ± 1.6 and 304.1 ± 1.5 kg, respectively), but greater ($P < 0.01$) than that of dams 4 to 8 yr old dams (302.4 ± 1.5 kg). Progeny of dams ≥9 yr old had the lowest milk solids production in first ($P < 0.001$; 297.8 ± 1.6 kg), second ($P < 0.001$; 341.6 ± 1.8 kg), and third lactations ($P < 0.01$; 393.2 ± 2.4 kg). Heifers that were the progeny of 2-yr-old dams produced the greatest ($P < 0.05$) milk solids yields in second lactation (Table 4).

Energy-corrected milk yields were greater ($P < 0.05$) for the progeny of 2-yr-old dams compared with the progeny of dams ≥9 yr old for all 3 lactations (Table 4). Similarly, the progeny of 2-yr-old dams produced greater ($P < 0.01$) ECM and milk solids in first and second lactation than did the progeny of dams 4 to 8 yr old, but there was no difference by third lactation (Table 4).

Table 4. Least squares means ± SEM for milk solids and ECM yields in first, second, and third lactation and accumulated over 3 parities (three-parity) for dairy heifers that were the progeny of 2-yr-old, 3-yr-old, 4- to 8-yr-old, or 9-yr-old and older dams

	Age of dam			
Lactation	2 yr	3 yr	4–8 yr	≥9 yr
Milk solids (kg)				
First	$304.9^{c} \pm 1.6$	$304.1^{c} \pm 1.5$	$302.4^{b} \pm 1.5$	$297.8^{a} \pm 1.6$
Second	$350.5^{d} \pm 1.8$	$348.7^{c} \pm 1.7$	$347.6^{b} \pm 1.7$	$341.6^{a} \pm 1.8$
Third	$397.9^{bc} \pm 2.6$	$398.6^{c} \pm 2.3$	$396.8^{b} \pm 2.2$	$393.2^{a} \pm 2.4$
Three-parity	$811.7^{b} \pm 9.0$	$806.0^{b} \pm 7.7$	$796.2^{a} \pm 7.4$	$789.4^{a} \pm 8.4$
ECM (kg)				
First	$3{,}976^{c} \pm 21$	$3{,}972^{c} \pm 20$	$3{,}951^{b} \pm 19$	$3{,}893^{a} \pm 20$
Second	$4{,}565^{c} \pm 24$	$4{,}550^{bc} \pm 22$	$4{,}538^{b} \pm 22$	$4{,}463^{a} \pm 23$
Third	$5{,}178^{bc} \pm 33$	$5{,}196^{c} \pm 30$	$5{,}175^{b} \pm 29$	$5{,}131^{a} \pm 32$
Three-parity	$10{,}574^{b} \pm 117$	$10{,}518^{b} \pm 101$	$10{,}396^{a} \pm 96$	$10{,}314^{a} \pm 110$

[a–d]Values with differing superscripts within a row indicate significant differences at $P < 0.05$.

The accumulated 3-parity ECM yields were 10,574 ± 117 and 10,518 ± 101 kg for the progeny of 2- and 3-yr-old dams, respectively, greater than the ECM yields of the progeny of dams 4 to 8 yr old (10,396 ± 96 kg) and ≥9 yr old (10,314 ± 110 kg; Table 4).

DISCUSSION

As expected, heifers that were the progeny of 2-yr-old dams were lighter than the progeny of older dams (Kertz et al., 1997; Place et al., 1998; Heinrichs et al., 2005; Hickson et al., 2015). Although small, the difference in BW is likely to be due to 2-yr-old heifers being lighter during pregnancy than older cows (Kertz et al., 1997, Livestock Improvement Corporation and DairyNZ, 2018), as they are yet to attain mature BW. The data presented in this study showed that heifers that were the progeny of 2-yr-old dams had greater proportions of Jersey compared with heifers that were the progeny of older dams and, therefore, were expected to be lighter (Handcock et al., 2019a). This was evident in the mean BW BV, which were −13.79 kg for the progeny of 2-yr-old dams and 3.81 kg for dams 4 to 8 yr old (difference of 17.6 kg). The statistical model used for BW in the current study corrected for the breed composition of the heifer, which reduced the difference between heifers born from 2-yr-old compared with older dams. For example, the breed-adjusted means for 21-mo BW reported in the current study were 411.6 and 415.9 kg for the progeny of dams 2 yr old and 4 to 8 yr old, respectively (difference of 4.3 kg), whereas, the unadjusted means for BW at 21 mo of age were 414.8 kg and 426.5 kg for the progeny of dams 2 yr old and 4 to 8 yr old, respectively (difference of 11.7 kg). Therefore, the observed differences in BW of the progeny of 2-yr-old dams compared with the progeny of mixed-age dams were mainly due to differences in breed composition, with only a small difference due to age-of-dam effects. Furthermore, the average milk solids production of Holstein-Friesian-Jersey crossbred cows in New Zealand aged ≥9 yr old was 368.1 kg compared with 394.2 kg for cows 4 to 8 yr old and 297.0 kg for 2-yr-old cows (Livestock Improvement Corporation and DairyNZ, 2018). Further studies are required to evaluate the association between dam milk production and calf size.

Previous research has demonstrated a positive relationship between BW before first calving and milk production (van der Waaij et al., 1997; McNaughton and Lopdell, 2013; Handcock et al., 2019b). However, in the current study, the progeny of 2-yr-old heifers produced significantly greater milk solids and ECM than did the progeny of dams 4 to 8 yr old and ≥9 yr old in first and second lactation, even though they were lighter. It is important to note that although the difference in milk solids yields between the progeny of 2-yr-old dams and 4- to 8-yr-old dams was significant, numerically they were differences of 2.5 kg in first and 2.9 kg in second lactation that may not result in meaningful differences on a farm scale. Results from Austrian dual-purpose Simmental cows also showed that the progeny of younger dams produced greater ECM yields than did older dams (Fuerst-Waltl et al., 2004). The progeny of dams ≥9 yr old in the current study had the lowest milk production, similar to that reported by Fuerst-Waltl et al. (2004). Genetic merit is likely to explain some of the differences observed, with the progeny of dams ≥9 yr old having lower BrW than that of the progeny of younger dams. However, the BrW differences appear to be driven by the lower milk volume and BW BV of the progeny of 2-yr-old dams compared with those of older dams, and not by superior fat or protein BV. Both milk volume and BW BV have a negative economic value for calculating BrW (Livestock Improvement Corporation and DairyNZ, 2018); therefore, lower values are desirable for these 2 traits. Furthermore, the mean milk volume and BW BV of Friesian bulls (767 kg and 46.2 kg, respectively) were greater than the mean milk volume and BW BV of Jersey bulls (−475 and −53.2 kg, respectively; Livestock Improvement Corporation and DairyNZ, 2018). Therefore, some of the differences in BrW between the progeny of 2-yr-old dams and the progeny of older dams are likely to be a function of breed, as the progeny of 2-yr-old dams had greater proportions of J compared with older dams.

The model used by Fuerst-Waltl et al. (2004) included the additive genetic effect of animal to correct for any bias from older dams having lower genetic merit than that of younger dams. We attempted to correct for differences in genetic merit based on dam age with inconsistent results (data not shown). One reason for the inconsistency of results may be due to Mendelian sampling, which means that an individual heifers' true genetic merit is not exactly halfway between that of her dam and sire. The precalving BV and BrW presented in the current study are based only on the performance of an individuals' ancestors. Once a heifer has begun to lactate and been herd tested, her own milk-production data feeds into the estimation of BV, creating a better estimate of her true genetic merit for milk production. Although a more accurate estimate of BV, using a heifer's first-lactation milk production to estimate her BV creates a confounded relationship between BV and milk production if BV are used to correct for genetic merit. In addition, BV already account for breed differences (DairyNZ, 2016), therefore, BV and breed proportions cannot be included in the same statistical models. Further research is required to compare heifers born from

2-yr-olds with those from older dams of similar genetic merit and breed makeup, to confirm the effect age of dam has on BW and milk production independent of genetic and breed effects. Nevertheless, the results presented here are relevant at the industry level, where younger dams typically do have better genetic merit and so these effects occur in tandem.

There is a potential bias from considering only cows that survived to lactate each year if particular cows had better survival than others. Therefore, the data in the current study includes each lactation for the surviving cows as well as the accumulated milk production of all cows that were old enough to have completed 3 lactations, regardless of whether they did or not (Handcock et al., 2019b). Based on their first-, second-, and third-lactation production and results from previous studies (Macdonald et al., 2005; Lembeye et al., 2016), the mean accumulated 3-parity yields for the age of dam groups is less than what would be expected if only cows that had completed all 3 lactations were included. This reflects that approximately 34% of the 67,833 heifers in the current study for 3-parity yields failed to complete all 3 lactations (Handcock et al., 2019b). The costs of rearing a heifer are incurred regardless of how long she remains in the herd. Analyzing the relationship including only the survivors does not truly describe the effect of age of dam on milk production, as it does not take into account how long the heifers actually remained productive for, in addition to the decreased milk production (Archer et al., 2013). To the authors knowledge, there are no similar studies on accumulated milk production for the progeny of different aged dams.

Although there were clear differences in milk production among the progeny of dams differing in age, there were only small differences in the reproductive and survival variables tested in the current study. The stayability to each year for the progeny of 2-yr-old dams was either similar to or slightly less than that of the progeny of mixed-age dams. Although the differences were significant, most were practically negligible, for example, stayability to third calving was 61.9% for the progeny of 3-yr-old dams, significantly greater than 60.7% for the progeny of 2-yr-old dams. For an average New Zealand herd with 86 replacement heifers reared each year, this equates to a difference of 1 cow surviving to third calving (52 vs. 53 cows).

Results of a simulation study showed that the greatest effect on genetic gain (measured as BrW) was achieved by excluding the lowest BrW cows from producing replacement heifers (Johnson et al., 2018). Inclusion of the highest BrW cows and 15-mo-old heifers mated with artificial insemination was also recommended as a method to generate sufficient replacement heifers of high genetic merit (Johnson et al., 2018). Results from the present study indicate that the progeny of young dams are expected to be marginally smaller than the progeny of older dams, provided 15-mo-old heifers are mated to bulls of similar breed makeup to those used in the main herd. Importantly, the milk production of these heifers born from 2-yr-old dams is expected to be equal to that of 3-yr-old dams, and greater than that of older dams. Although the reproductive performance (as measured by calving and recalving rates) was better for the progeny of dams ≥9 yr old, the numerical differences were very small, and on a farm scale, it is unlikely to be of practical significance. The results from the current study indicated that retaining replacements from cows aged ≥9 yr old would not be recommended, as these heifers had lower genetic merit and produced less milk than did those with younger dams.

ACKNOWLEDGMENTS

The authors acknowledge Katie Carnie (Livestock Improvement Corporation, Hamilton, New Zealand) for extracting the data provided by Livestock Improvement Corporation. The first author was funded by Massey University. The authors have not stated any conflicts of interest.

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