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Growth rates of contract-reared versus home-reared replacement dairy heifers

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ABSTRACT

Successful heifer rearing is dependent on achieving optimal average daily gain (**ADG**) targets to calve for the first time at 24 months. Whilst dairy farmers internationally have traditionally managed their heifers on-farm to achieve these targets, recent dairy herd expansion within Europe has resulted in increased demand for labour-saving heifer-rearing strategies, such as off-farm contractrearing. However, loss of direct influence on the day-to-day management decisions affecting the ability of heifers to grow adequately to achieve this age of first calving may represent a potential barrier to uptake. Hence, the aim of this longitudinal observational study was to compare the growth rates of contract- vs home-reared heifers. Approximately 6 500 heifers from 120 commercial Irish dairy farms were enrolled in a 3-year study. For 65 of these farms, heifers were reared at a contract-rearing facility. For the remaining 55 farms, heifers were reared on their home farm. Over the course of 20 months from birth until precalving, heifers were examined and weighed at four farm visits. The relationship between several independent variables (farm type, herd size, heifer breed, economic breeding index (**EBI**) and health events) and ADG at different time points was investigated and analysed utilising linear mixed models. Overall ADG for heifers throughout the rearing period was 0.71 kg/day. There was a significant association between farm type and ADG for all five linear ADG models; home-reared heifers grew, on average, 0.025, 0.039, 0.11 and 0.059 kg/day more than contract-reared heifers between visit 1 and visit 4 (overall ADG), visit 1 and visit 2, visit 2 and visit 3 and visit 1 and visit 3, respectively. The occurrence of diarrhoea during farm visit 2 (median age 8.5 months) was associated with a significant reduction in ADG between visit 3 and visit 4. Calf-hood disease (diarrhoea, respiratory disease or navel ill) was not associated with the growth rate during any of the subsequent visit periods. While home-reared heifers had greater ADG during four of the five periods studied, median heifer ADG in both cohorts exceeded the minimum published target weight gains at each developmental stage required for heifers to reach puberty, conceive at 15 months and calve for the first time at 24 months. Importantly, there was wide variation both within enterprises and between farms. It was concluded that while the absolute difference in daily growth rates of home- and contract-reared heifers was minimal, when considered in the context of the entire heifer-rearing period, these growth rate differences have the potential to impact the future reproductive and milk production performance of heifers.

Implications

This study was conducted in the context of labour and land constraints on dairy farms with expanding herds post European milk quota abolition in 2015. Contractrearing is an option to manage these constraints, but its effects on heifer growth were unknown. From our results, we learned that contract-reared heifers had lower average daily gains from birth through to precalving than those of home-reared heifers but also there was wide variation both within enterprises and between farms. Dairy farmers, their agricultural advisors and veterinary practitioners will benefit from these results if they use them to improve the management of replacement dairy heifers.

Introduction

The increased labour requirements associated with large and expanding dairy herds, coupled with a shortage of skilled agricultural workers, have prompted increased interest in opportunities

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to outsource labour-intensive enterprises, such as heifer rearing. Contractrearing is a collaborative farming practice that involves replacement heifers being reared off-site by another farmer for a specified duration, typically from weaning to the point of calving (McCarthy et al., 2021a). A potential drawback of contract rearing for the dairy farmer is loss of control over the day-to-day management decisions that affect the ability of their heifers to grow sufficiently to reach developmental milestones. On the other hand, the specialist nature of contract-rearing farms may result in the implementation of optimal heifer management practices by these farmers, with a greater focus on attaining target growth rates at key developmental milestones than would be possible on dairy farms where the primary focus is usually on the lactating cows.

The benchmark metric of successful heifer rearing internationally is achieving an age-at-first calving (**AFC**) of 24 months, particularly in pasture-based milk production systems (Berry and Cromie, 2009). An AFC of 24 months is optimal to achieve maximum heifer-rearing cost savings by shortening the length of the non-productive period while concurrently minimising the possible detrimental biological effects associated with earlier calving, such as increased risk of dystocia, lower conception rates, reduced longevity and reduction in future milk production capacity (Froidmont et al., 2013; Atashi et al., 2021).

Achieving an AFC of 24 months is dependent on many factors including heifers surviving the rearing period, reaching puberty and subsequently conceiving at 15 months. As many farm management practices can influence heifer mortality and reproductive outcomes, measuring heifer growth rate serves as a proxy indicator of the success of all combined heifer-rearing practices. Attainment of sexual maturity is influenced by both BW and age, with 12–13 months at approximately 43% of mature BW being optimal to allow heifers to experience multiple oestrus events before breeding (Van Amburgh et al., 1998; Wathes et al., 2014). At breeding, heifers should have reached approximately 55% of mature BW (National Research Council, 2001) and for Holstein-Friesian (**HF**) and HF-Jersey crossbred heifers that are typical of pasture-based dairying, this equates to BWs of 350 kg and 300 kg, respectively (Kennedy and Murphy, 2017). Taking average birth weights of Irish HF and Jersey-cross heifers to be 34.4 kg and 32 kg, respectively (Animal Health Ireland, 2011; Costigan et al., 2021), achieving target breeding weights necessitates minimum average daily growth rates in the first year of 0.69 kg and 0.58 kg, respectively. In terms of future performance capacity, a recent Irish study showed that an average daily gain (**ADG**) of 0.8 kg/day in the prebreeding period was optimal to maximise first lactation milk yield and reproductive performance of heifers (Hayes et al., 2021).

Overgrowing heifers beyond 0.8 kg/day through liberal feeding with the intention of reducing AFC has been associated with several undesirable outcomes including increased risk of dystocia (Hoffman et al., 1994), reduced fertility (Brickell et al., 2009a), and increased feed costs (Tozer and Heinrichs, 2001). Similarly, underfeeding of heifers has a negative impact on future performance capacity. Rincker et al. (2011) demonstrated that heifers which grew at 0.44 kg/day had delayed onset of puberty when compared to heifers which grew at 0.68 kg/day. As a result, AFC was increased. Further to this, heifers fed to restrict ADG to 0.4 kg/day between 2 and 8 weeks of age had reduced total mammary parenchymal tissue when compared to heifers whose growth was unrestricted in this period (Brown et al., 2005). Impaired mammary growth in early life is correlated with reduced milk yield potential in later life (Sejrsen et al., 1982).

In Ireland, 70% of heifers calve between 22 and 26 months (Irish Cattle Breeding Federation (ICBF), 2020) and the median AFC is 25 months (Berry and Cromie, 2009). This is lower than the average AFC in many countries, including Italy (28.1 months) (Pirlo et al., 2000), the UK (29.1 months) (Eastham et al., 2018), Belgium and the Netherlands (25.8 months) (Van Eetvelde et al., 2020) and the US (26.9 months for Holstein and 25.6 months for Jersey breeds) (Hare et al., 2006). However, there appears to be scope for improvement in the average AFC of the national dairy herd towards the 24-month target through the implementation of appropriate heifer management strategies (Hayes et al., 2019).

According to the National Farm Survey, approximately 5% of Irish dairy farmers were using contract-rearing services in 2015 (Hennessy and Moran, 2016). This figure is expected to rise, however, in line with continued expansion and increased specialisation of dairy farms. Internationally, contract rearing of replacement heifers is also becoming increasingly common,for example, in the USA (Hadley et al., 2002, Bir et al., 2017), New Zealand (Cvitanovich, 2016) and Australia (AusVet Animal Health Services, 2005). According to United States Department of Agriculture figures, 9.3% of US dairy farmers reported to rear at least 'some' heifers in specialist heifer-rearing operations (Raiser, 2012). While several studies have reported on target heifer growth rates both in Ireland and internationally, to the authors' knowledge, there are no published studies comparing the growth performance of contract- and home-reared heifers in an Irish or international context. Given that ADG and AFC are critical metrics in heifer development, this is a major knowledge gap about this growing specialist enterprise internationally.

By focusing on one enterprise, specialist contract-rearers may be better able to manage heifers to achieve optimal growth rates to ensure an AFC of 24 months than dairy farmers rearing their own replacements and managing the milking herd. The aim of this study was thus to test this hypothesis that heifers reared at a contract-rearers would achieve higher ADGs than those reared on their farm of origin.

Material and methods

Herd recruitment

Herds were recruited to this study as previously described in (McCarthy et al., 2021a). Briefly, through a multistep process involving the national cattle breeding organisation (**ICBF**) and several Irish farming stakeholder bodies and media awareness campaigns, one hundred and twenty dairy farmers were recruited in the spring of 2018 to a 3-year longitudinal study to investigate the risks to animal health associated with contract heifer rearing.

Of the recruited farmers, 55 were rearing their own heifers (home-rearing) and 65 were sending their heifers off-farm to be reared at a specialist contract-rearing farm (contractrearing). The contract-rearing farmers providing rearing services to these farmers were concurrently recruited to the study ($n = 57$; A proportion of the recruited contract-rearing farmers ($n = 8$) were providing rearing services to two or more of the recruited dairy farmers). For the majority of contract-rearing farmers, contractrearing of replacement dairy heifers was their sole farm enterprise (77%), with the remaining farmers concurrently operating beef, sheep or tillage farming enterprises (McCarthy et al., 2021a). All regions within Ireland were represented, however, the highest density of farms was in county Cork, reflecting the distribution of the national dairy cow population.

Farm visits

All heifer calves born on study farms were recruited to the study in spring 2018. At recruitment, information regarding herd calving pattern was established and farm visits were timed to coincide with the maximal availability of heifer calves for examination, weighing and sampling. On the majority of farms, calving commenced in early February and a large proportion of the herd was expected to calve in the subsequent 6-week period. As a result, farms were visited for the first time at the end of February. Where possible, the order in which farms were visited was maintained across the four sampling periods, to ensure an equal period was observed between data collection timepoints. Given that the average AFC of Irish heifers is 25 months (Berry and Cromie, 2009), the likely conception window was between 14 and 16 months. Thus, the third farm visit was conducted when the median age of heifers was 12.7 months, to represent prebreeding weight.

Between February 2018 and December 2019, all heifers born on study dairy farms during spring 2018 were weighed at 4 time points by the research team. During the first farm visit period (**V1**) between February and May 2018, the median heifer calf age was 41 days. The second farm visit (**V2**) was conducted between September and December 2018 when the median age of heifers was 8.5 months. The third farm visit (**V3**) was conducted when the median age of heifers was 12.7 months between January and May 2019. The fourth farm visit (**V4**) was conducted between September and December 2019 when the median age of heifers was 20 months old. Each heifer was identified using their unique ear tag number, and their BW was measured using a portable weigh platform with true-test load bars (Tru-Test EziWeigh5i system). Calibration of the weighing system was performed at the beginning of each weigh session.

Heifer data

Approximately 6 500 heifers were enrolled in the study at the first farm visit. Over the course of the study, loss of heifers occurred due to farm drop-out ($n = 7$ farms), incomplete herd data ($n = 2$), mortality and sale of heifers resulting in data being available for 4 284 heifers on 111 dairy farms ($n = 60$ contract-rearing dairy farms, $n = 51$ home-rearing dairy farms) for all timepoints. The birth dates, breed designation, **EBI** (a genetic selection tool derived from the breeding values of dairy animals for milk production traits, health, maintenance, management, fertility and longevity in the herd weighted by their respective economic values (Berry et al., 2005)), EBI maintenance sub-index (**EBI MSI**) and parentage information of each heifer were extracted from the ICBF database. Heifers were categorised as purebred Holstein if a minimum of 87.5% of their breed fraction was from that population, in accordance with other Irish studies (Berry et al., 2014; Coffey et al., 2016). Where heifer breed composition was Holstein and Friesian only, heifers were categorised as HF. If HF was the predominant breed fraction with the remaining fractions made up Jersey, the heifer was categorised as a HF-Jersey crossbred. The remaining breed category was made up of Simmental, Montbeliarde, Norwegian Red, HF-Norwegian Red crossbreds and crossbred combinations of these breeds.

Morbidity data

Health data for study heifers were collected as described by McCarthy et al. (2021b) Briefly, during each visit period, all heifers were clinically assessed and a health score of 0 to 3 [normal (0), very abnormal (3)] was assigned to each clinical parameter using a modified version of the Wisconsin clinical health scoring system (McGuirk and Peek, 2014). Scores were recorded for each of the following clinical parameters: ocular discharge, nasal discharge, rectal temperature, presence of cough, navel abnormalities, appearance of joints and faecal consistency. Health scores were subsequently dichotomised using clinical thresholds. Heifers with a rectal temperature of ≥ 39.5 °C were considered pyrexic, in agreement with the threshold used in similar studies (Mahendran et al., 2017). For the remaining health outcomes, a score of ≥ 1 was considered abnormal. The cumulative scores of rectal temperature, nasal and eye discharge, and cough were used to calculate an overall respiratory score. Calves with a score of ≥ 5 (out of a possible 15) were considered to have respiratory disease (McGuirk and Peek, 2014). Calves with a faecal score of ≥ 2 were considered to have diarrhoea (McGuirk, 2008; Cramer et al., 2019). Calves with a navel score of ≥ 1 were diagnosed with navel ill.

Additionally, within each visit period, heifers were assigned a score of 0 (absence of disease) or 1 (presence of clinical disease) for diarrhoea, respiratory disease and navel ill. Finally, visit periods were considered cumulatively and heifers were assigned a score of 0 if they remained healthy across all 4 farm visits and 1 if they experienced at least one disease event over the course of the study.

Statistical analysis

To ascertain the relationship between heifer-rearing method (home-reared vs contract-reared) and performance outcomes, the dependent variable was ADG. Independent variables were farm type (contract-rearing vs home-rearing), prebreeding BW, heifer EBI maintenance sub-index, heifer cohort size and herd size, diarrhoea at each visit, pneumonia at each visit, navel ill during spring 1 and overall presence or absence of disease (as defined above) throughout the study period. For contract-reared heifers, the practice of commingling of heifers from multiple sources (yes/no) and if heifers were reared on single-origin or multi-origin rearing farms were also included as independent variables for all study periods.

Since we considered that the ADG of heifers would not be linear across the entire observation period, we conducted separate analyses for each observation interval. Therefore, the ADG of heifers was considered between visit 1 and visit 2 (V1-2), between visit 2 and visit 3 (V2-3), between visit 3 and visit 4 (V3-4) and between visit 1 and visit 3 (V1-3). In addition, for the overall ADG of each calf over the time period, we conducted separate linear regression models for each individual calf with weight at each of the four observation points modelled as a function of age. The coefficient of age was extracted from each of these models and used as the overall ADG for each calf over the observation period (approximately 1–22 months of age).

Data analysis was conducted in RStudio (Rstudio Team, version 1.4.1717). The distribution of independent variables was assessed using the Kolmogorov-Smirnov test of normality. Mean and standard deviations were calculated for normally distributed variables, and median and interquartile range (**IQR**) were calculated for non-normally distributed data. Average daily growth rates were examined for each period, and growth rate outliers (outside the mean ±3 SD) associated with error in BW recordings were reviewed and removed ($n = 10$) (Yang and Hutcheon, 2016).

Univariable analysis was performed to evaluate the relationships between each of the following variables and the outcome variable (ADG); heifer EBI and maintenance sub-index, heifer breed, morbidity events, herd size and heifer cohort size. Variables significant at $P < 0.2$ were brought forward to a multivariable linear mixed model. Variables were also screened for correlation. Where variables were found to be correlated, the variable resulting in the best model fit according to the lowest Akaike Information Criterion was used in the model. Continuous variables such as EBI and EBI maintenance sub-index, heifer cohort and herd size were plotted against ADG to determine the likely shape of any association between the variables. Those variables that appeared to have a non-linear relationship with the dependent variable were categorised then log-transformed and transformed to the power of 2. Each of these transformed variable versions, along with the linear version of the variable, was tested univariately in each ADG model, and the Akaike Information Criterion was used to select the most appropriate version of the variable to include in the multivariate analysis.

Forward stepwise elimination was used to construct five multivariable mixed linear regression models with ADG for each period as the dependent variable with farm and month of birth as random effects. Breed was forced into each model, regardless of its significance, to account for breed variation in ADG. After the addition of each variable, the *P*-values for all variables in the model were calculated, and variables with a *P*-value less than 0.05 were removed. All potential interactions between the explanatory variables in each model were examined and included in the final model if significant (*P*-value < 0.05) according to the Wald test. *P*-values were manually calculated from the estimates and SEs as $P = \exp(-0.717 \times Z - 0.416 \times Z2)$, where Z equals the effect estimate divided by the SE (Altman and Bland, 2011).

Results

Descriptive analysis

Weight data were available for 4 284 heifers for all time points (2 667 contract-reared heifers from 60 dairy farmers sending heifers to rearing unit and 1 617 home-reared heifers, on 51 farms). Heifer breed was represented in the data as follows; 34% were HF, 58.5% were HF-Jersey crossbreds, 6.8% were purebred Holstein and the remaining 0.6% were Montbeliarde, Simmental, Norwegian Red and HF-Norwegian cross breeds.

Overall ADG between visit 1 and visit 4 ranged from 0.37 to 1 kg/day with a median of 0.71 kg/day (IQR 0.6–0.81); intermediate ADG results are shown in Table 1. Descriptive statistics for BW and age of heifers at each time point are shown in Table 2. Descriptive statistics relating to ADG for home- and contract-reared heifers are shown in Table 3. Descriptive statistics for ADG and BW by breed category are shown in Tables 4 and 5.

Univariate analysis

Overall average daily gain

Following univariate analysis, the following variables were selected for inclusion in the multivariable overall ADG model; farm type, herd size, breed, EBI maintenance sub-index and occurrence of diarrhoea during any visit throughout the study period.

Average daily gain V1-2

Following univariate analysis, the following variables were selected for inclusion in the multivariable ADG V1-2 model; farm type, breed, herd size, EBI maintenance sub-index and occurrence of navel ill during the first spring visit period.

Average daily gain V2-3

Following univariate analysis, the following variables were selected for inclusion in the multivariable ADG V2-3 model; farm type, commingling of heifers permitted at rearing unit, breed, diagnosis of respiratory disease, navel ill or pyrexia during the first visit period, EBI maintenance sub-index and heifer cohort size.

Average daily gain V3-4

Following univariate analysis, the following variables were selected for inclusion in the multivariable ADG V3-4 model; farm type, breed, herd size, diagnosis of respiratory disease, navel ill or pyrexia during the first visit (V1) and third (V3) visit periods, EBI maintenance sub-index and diagnosis of diarrhoea during the first autumn visit period (V2).

Average daily gain V1-3

Following univariate analysis, the following variables were selected for inclusion in the multivariable ADG V1-3 model; EBI maintenance sub-index, farm type, breed, calf-hood respiratory disease, calf-hood diarrhoea and herd size category.

Multivariate analysis

The output from the multivariate analysis is presented in Table 6.

Overall average daily gain

In the final model, farm type and breed (*P* < 0.001) were significantly associated with overall ADG; home-reared heifers grew, on average, 0.025 kg more per day than contract-reared heifers.

Average daily gain V1-2

Farm type (*P* = 0.036) and heifer EBI maintenance sub-index (*P* = 0.001) were significantly associated with ADG V1-2; home-reared heifers grew, on average, 0.039 kg/day more per day than heifers on contract-rearing farms. Breed was not significant but was included in the model as a covariate. The interaction between breed and EBI maintenance sub-index was significant.

Average daily gain V2-3

Farm type (*P* < 0.001) and EBI maintenance sub-index were significantly (*P* < 0.001) associated with ADG V2-3; home-reared heifers grew, on average, 0.11 kg/day more than heifers on contract-rearing farms. Breed was retained in the model.

Average daily gain V3-4

Farm type (*P* = 0.004), EBI maintenance sub-index (*P* < 0.001) and occurrence of diarrhoea (faecal score of ≥ 2) (*P* = 0.04) during the first autumn visit period were significantly associated with ADG V3-4. On average, contract-reared heifers grew 0.069 kg/day

Table 1
Average daily gain (ADG) of dairy heifers on 111 farms during five periods; overall ADG between visit 1 and visit 4, visit 1 and visit 2 (V1-2), visit 2 and visit 3 (V2-3), visit 3 and visit 4 (V3-4) and visit 1 and visit 3 (V1-3).

Visit period interval[1]	*n*	Median ADG (kg/day)	IQR	Minimum (kg/day)	Maximum (kg/day)
V1-2	4 604	0.74	0.59–0.89	0.23	1.29
V2-3	5 013	0.55	−0.28–0.82	−0.8	1.60
V3-4	4 932	0.78	0.58–0.98	0.15	1.70
V1-3	4 682	0.67	0.53–0.81	0.25	1.1
Overall (V1-4)	4 546	0.71	0.61–0.81	0.37	1.0

Abbreviations: IQR = Interquartile range.
[1] During the first farm visit period (V1) between February and May 2018, the median heifer calf age was 41 days. The second farm visit (V2) was conducted between September and December 2018 when the median age of heifers was 8.5 months (259 days). The third farm visit (V3) was conducted when the median age of heifers was 12.7 months (386 days) between January and May 2019. The fourth farm visit (V4) was conducted between September and December 2019 when the median age of heifers was 20 months old (608 days).

Table 2
Age and BW of heifers at four timepoints precalving on 111 dairy farms.

Visit period	*n*	Median age (days)	IQR (days)	Median weight (kg)	IQR (kg)	Minimum (kg)	Maximum (kg)
1	4 835	41	15–67	56	36–76	18.6	257
2	5 132	261	223–299	218	171–265	116	396
3	5 215	387	345–429	288	236–340	148	472
4	5 073	613	481–694	462	390–534	287	691

Abbreviations: IQR = Interquartile range.

Table 3
Average daily gain (ADG) of contract- and home-reared heifers at each of five farm visit intervals.

	Rearing strategy	
Visit period	Contract-rearing	Home-rearing
ADG V1-2		
Median ADG (kg/day)	0.70	0.76
Minimum (kg/day)	0.33	0.23
Maximum (kg/day)	1.10	1.30
ADG V2-3		
Median ADG (kg/day)	0.51	0.64
Minimum (kg/day)	−0.82	−0.7
Maximum (kg/day)	1.60	1.60
ADG V3-4		
Median ADG (kg/day)	0.80	0.77
Minimum (kg/day)	0.16	0.15
Maximum (kg/day)	1.70	1.50
ADG V1-3		
Median ADG (kg/day)	0.65	0.71
Minimum (kg/day)	0.38	0.35
Maximum (kg/day)	1.0	1.10
Overall ADG (V1-4)		
Median ADG (kg/day)	0.70	0.73
Minimum (kg/day)	0.42	0.38
Maximum (kg/day)	1.0	1.0

Table 4
Average daily gain (ADG) of dairy heifers by breed at five farm visit intervals (median, 95% confidence intervals).

Visit period interval	Holstein-Friesian	Holstein-Friesian-Jersey crossbred	Holstein	MO, SI, NR, NR-HF
V1-2	0.75 (0.74–0.76)	0.73 (0.72–0.73)	0.74 (0.73–0.76)	0.64 (0.55–0.67)
V2-3	0.62 (0.6–0.63)	0.51 (0.50–0.52)	0.62 (0.57–0.65)	0.69 (0.64–0.83)
V3-4	0.81 (0.80–0.82)	0.76 (0.76–0.77)	0.80 (0.78–0.84)	0.87 (0.84–0.89)
V1-3	0.70 (0.70–0.71)	0.65 (0.65–0.66)	0.7(0.69–0.71)	0.63 (0.61–0.67)
Overall (V1-4)	0.74 (0.74–0.75)	0.69 (0.69–0.70)	0.74 (0.74–0.75)	0.75 (0.72–0.78)

Abbreviations: MO = Montbeliarde, SI = Simmental, NR = Norwegian Red, NR-HF = Holstein-Friesian Norwegian red crossbreds.

more than home-reared heifers during this period. Heifers that experienced diarrhoea during the first autumn visit period grew, on average, 0.05 kg/day less than healthy heifers. The interactions between EBI maintenance sub-index and farm type ($P = 0.047$) and occurrence of pyrexia at farm visit 3 ($P = 0.002$) were also significant.

Average daily gain V1-3 (prebreeding growth rate)

Farm type ($P < 0.001$) and EBI maintenance sub-index ($P < 0.001$) were significantly associated with ADG V1-3; home-reared heifers grew, on average, 0.06 kg/day more than heifers on contract-rearing farms. The interaction between breed and EBI maintenance sub-index was significant ($P < 0.001$).

Economic breeding index maintenance sub-index and average daily gain

Economic breeding index maintenance sub-index was associated with ADG, and an interaction between breed and EBI MSI was also observed. This was expected, given that EBI MSI serves as a genetic predictor of mature BW, and thus indirectly the ADG of heifers in the rearing period (Ramsbottom and McParland, 2018).

Discussion

To the authors' knowledge, this is the first study internationally to report the effects of sending heifers off the home farm to be managed by a contract-rearer on replacement heifer precalving growth rates. Given the increasing size of dairy herds around the world, this practice may become more common in future, hence, its implications for the key developmental metric, ADG, are critical to both dairy herd expansion and contract rearing as a vertically integrated enterprise within dairy industries internationally.

Overall average daily gain

The results reported here indicate that home-reared heifers achieved higher growth rates between birth and precalving than heifers grown on contract-rearing farms. Given that contract heifer

Table 5
Body weight (kg) of dairy heifers by breed at four farm visit periods (median, minimum–maximum).

Visit period	Holstein-Friesian	Holstein-Friesian Jersey crossbred	Holstein	MO, SI, NR, NR-HF
1	62.4 (28–55)	52.2 (19–198)	62.8 (29–257)	79.5 (37–119)
2	231 (122–396)	212 (116–322)	225 (129–368)	201 (143–300)
3	307 (172–446)	279 (148–404)	301 (205–472)	284 (223–392)
4	489 (328–691)	445 (287–620)	485 (338–636)	506 (414–588)

Abbreviations: MO = Montbeliarde, SI = Simmental, NR = Norwegian Red, NR-HF = Holstein-Friesian Norwegian red crossbreds.

rearing is typically the sole farm enterprise of Irish contract-rearing farmers (McCarthy et al., 2021a), it was hypothesised that streamlining of management practices would allow heifers on these farms to achieve greater growth rates compared to home-reared heifers. This hypothesis was refuted. A possible explanation for this may be the relative lack of dairy specialist knowledge associated with some contract-rearing farmers who may have previously been engaged in other farm enterprises such as beef and sheep farming. Given the different management interventions associated with beef or sheep farming compared to rearing of replacement dairy heifers, it is possible that some contract-rearing farmers may benefit from advisory extension relating specifically to dairy heifer management, particularly for target BW and growth rates for key developmental stages during the rearing period.

In addition to these technical reasons for refuting the hypothesis, it is possible that contract-rearers may be less 'invested' both from an economic long-term perspective and from an emotional perspective in the contract-reared heifers. This may be because they do not benefit from the long-term outcomes of heifer rearing and in the latter case because they have not invested both economically and emotionally in the breeding, care and management of these future herd replacements. Given these, speculative, possible reasons for the heifer growth outcomes, in addition to technical advisory assistance, social science research on farmer attitudes to heifer rearing may be warranted.

In addition, inadvertent selection bias associated with recruitment of home-rearing herds may have resulted in the inclusion of more progressive than average dairy farmers, with increased awareness of heifer growth targets. This is because these farmers had larger than average herds, as they were matched with dairy herds engaged in contractrearing who, by their nature, were considerably larger than average (herd size 198 cows). Management practices during the early rearing period (before heifers were moved to the rearing unit) on dairy farms sending heifers to a rearing unit were broadly similar to those implemented by dairy farmers rearing their own heifers (McCarthy et al., 2021a), However, if the former cohort of farmers had reared their own replacement heifers for the duration of the rearing period, division of resources between the milking herd and heifer cohort may have proved more challenging, resulting in more unfavourable growth outcomes for heifers than were achieved by contract-rearing farmers.

Despite the statistically significant difference in overall ADG, it is difficult to draw firm conclusions on the heifer growth benefits of one rearing strategy over the other, given the marginal absolute ADG increase (0.025 kg/day) associated with home-vs contract rearing. For example, a home-reared HF heifer, with a typical, birthweight of 34 kg, would reach target precalving weight target (550 kg) at 710 days, compared to 737 days for contract-reared heifers. The biological consequences of such a small growth rate difference are difficult to predict in terms of the future milk production and reproductive capacity of such heifers. For example, an analysis of AFC between the two heifer cohorts used in the present study found no significant differences between groups (McCarthy et al., 2022).

It was reassuring to find that commingling of heifers from multiple sources and the number of farms sending heifers to the rearing unit were not associated with growth outcomes for heifers on contract-rearing farms. While the majority of contract-rearing farms were singleorigin (70%) in this study, future growth of the industry may result in an increase in the number of multi-origin rearing farms.

The percentage of contract- and home-reared heifers that exceeded the minimum target growth rate of 0.69 kg/day was 58% and 73%, respectively. Across farm types and breeds, the median overall ADG achieved by study heifers was comparable to that reported in a recent Irish study by Hayes et al. (2019), who reported an ADG of 0.7 kg in heifers between birth and 2 years of age.

Prebreeding average daily gain (V1-3)

In the current study, the prebreeding growth rate is best represented by ADG recorded between visit 1 and visit 3. Across farm types, the median ADG in study heifers for this period was 0.67 kg, slightly lower than that reported by Hayes et al. (2021) for Irish heifers (0.70 kg/d) during the same period. There was considerably less breed variation in their study compared to our study; however, the majority of their heifers (85%) were HF. In our study, the predominant breed type was HF Jersey crossbreds. Holstein-Friesian cows are heavier and later maturing than HF-Jersey crossbred cows (Handcock et al., 2019) which may account for the slightly higher growth rate in the study by Hayes et al. (2021). Across farm types, the median prebreeding ADG of HF (0.7 kg/day) and HF-Jersey (0.65 kg/day) heifers exceeded minimum target growth rates (0.69 kg/day and 0.58 kg/day HF and Jersey-cross heifers, respectively) required for heifers to reach puberty before 15 months (Brickell et al., 2009a; Dhakal et al., 2013; Kennedy and Murphy, 2017). According to Zanton and Heinrichs (2005), a prepubertal growth rate of 0.8 kg/day is optimal to maximise milk production in the first lactation. In the context of the Irish production system, Hayes et al. (2021) reported a prebreeding ADG of 0.82 kg/day was optimal to both enhance reproductive efficiency and maximise first lactation milk yield. This is considerably higher than the median growth rate achieved for heifers in the current study.

Rearing strategy

While home-reared heifers grew, on average, 0.059 kg/day more than heifers on contract-rearing farms during the prebreeding period, the median ADG across farm types for HF and HF-Jersey crossbred heifers exceeded published minimum prebreeding breed-specific target growth rates (Kennedy and Murphy, 2017). There was large variation in individual heifer growth rates across farms for this period (0.25–1.1 kg/day), consistent with the findings of several similar studies (Donovan et al., 1998; Brickell et al., 2009b). This was also reflected in the wide range of live weight recordings for heifers at the third farm visit, corresponding to the period prior to the commencement of the breeding

Table 6
Output from multivariable linear mixed models with farm and heifer birth month as random effects, demonstrating the effect of farm type, breed, EBI maintenance sub-index and health events on average daily gain (ADG) of heifers at different timepoints throughout the study period (ref = reference category).

	Overall ADG				ADG V1-2				ADG V2-3				ADG V3-4				ADG V1-3			
Variable	Estimate (ADG)	Lower CI (95%)	Upper CI (95%)	*P-value*	Estimate (ADG)	Lower CI (95%)	Upper CI (95%)	*P-value*	Estimate (ADG)	Lower CI (95%)	Upper CI (95%)	*P-value*	Estimate (ADG)	Lower CI (95%)	Upper CI (95%)	*P-value*	Estimate (ADG)	Lower CI (95%)	Upper CI (95%)	*P-value*
Farm type																				
Dairy farm	0.025	0.005	0.046	0.012*	0.039	0.002	0.076	0.036*	0.114	0.053	0.175	< 0.001*	−0.069	−0.115	−0.023	0.004*	0.059	0.027	0.091	< 0.001*
Contract-rearing (ref)	Reference category																			
Breed																				
HF	−0.004	−0.012	0.005	0.447	−0.009	−0.053	0.036	0.706	0.013	−0.006	0.033	0.187	−0.020	−0.036	−0.003	0.019*	−0.002	−0.017	0.012	0.761
HF-J	−0.027	−0.037	−0.017	< 0.001*	−0.012	−0.060	0.037	0.654	0.010	−0.013	0.033	0.397	−0.023	−0.042	−0.004	0.018*	−0.014	−0.030	0.002	0.076
MO, SI, NR	0.037	−0.017	0.09	0.180	−0.156	−0.594	0.282	0.495	0.074	−0.077	0.225	0.340	0.068	−0.065	0.202	0.321	−0.042	−0.146	0.062	0.436
HO	Reference category																			
EBI MSI					−0.004	−0.006	−0.002	< 0.001*	−0.002	−0.003	−0.001	< 0.001*	−0.005	−0.007	−0.004	< 0.001*	−0.004	−0.005	−0.003	< 0.001*
Diarrhoea at V2																				
Yes													0.048	0.001	0.095	0.043*				
No													Reference category							
Pyrexia at V3																				
Yes													−0.034	−0.073	0.005	0.087				
No													Reference category							
Interaction of EBI MSI and farm type													0.001	0.000	0.002	0.047*				
Interaction of EBI MSI and pyrexia at V3													0.003	0.001	0.005	0.002*				
Interaction of EBI MSI by breed																				
HF					0.001	0.000	0.003	0.115									0.001	0.000	0.002	0.096
HF-J					0.002	0.001	0.004	0.009*									0.002	0.001	0.003	0.001*
MO, SI, NR					0.012	0.006	0.019	< 0.001*									0.006	0.000	0.012	0.043*
HO						Reference category													Reference category	

Abbreviations: HF = Holstein-Friesian, HF-J = Holstein-Friesian Jersey crossbred, MO = Montbeliarde, SI = Simmental, NR = Norwegian Red, HO = Holstein, MSI = Maintenance sub-index of the Economic breeding index (EBI), CI = Confidence interval.

* Significant at $P \leq 0.05$.

period. Median BW of HF-Jersey and HF heifers, across farms, was 279 kg (range 148–404 kg) and 307 kg (range 172–446 kg), respectively. These values are lower than the target prebreeding BWs of 295 kg and 350 kg for HF-Jersey and HF heifers, respectively. There was, however, a wide variation in the age of heifers during this sampling period and the latter did not coincide exactly with the onset of the breeding season, which may account for some of these differences. Even taking these factors into account, a considerable number of study heifers on both farm types were below target BW to reach puberty before the commencement of the breeding season. This indicates considerable scope for improvement in pre breeding heifer-rearing practices on both farm types.

Average daily gain between V1-2

The ADG during this period reflects the growth of heifers between as close as possible to their birth and the first housing period, corresponding approximately to the first 8.5 months of life. Median heifer growth rate across farms for this period was 0.74 kg/day. While few studies have reported growth rates specifically for this period, several studies have reported comparable growth rates for heifers between birth and 6 months of age at 0.77 kg/day (Brickell et al., 2009b) and 0.74 kg/day (Donovan et al., 1998). There was a small, but significant, difference in ADG between home- and contract-reared heifers, with the former growing, on average, 0.039 kg/day more per day than the latter. This period encapsulates the movement of contract-reared heifers from the source dairy farm to the rearing unit. Transport stress, adaption to a new environment and feeding practices compounded by recent weaning, is a potential explanation for the lower growth rate experienced by contract-reared heifers during this period (Khan et al., 2007; Larios-Cueto et al., 2019).

The period of most rapid growth in dairy heifers is between 3 and 5 months of age (Handcock et al., 2019), typically corresponding to the period of turn out to pasture following weaning and introduction to concentrate feed in a pasture-based system. Feed conversion efficiency is highest among heifers of this age (Bach et al., 2021). Thus, optimising growth rate during this period through the inclusion of cheap, high-quality grazed grass in the diet represents an opportunity for producers to achieve maximum economic efficiency in heifer rearing. The significant effect of breed on ADG during this period was unsurprising, given the considerable breed variation in growth rates discussed above.

Average daily gain between V2-3

The ADG during this period corresponds to heifer growth during the first housing period. Median heifer ADG during this period was 0.55 kg/day, the lowest median ADG recorded during the study period. Typically, in the Irish pasture-based system of dairy production, heifers are housed between October and March (depending on weather conditions or pasture availability). With housing, a change in diet occurs, from grazed grass to grass silage with or without concentrate supplementation. There are several factors contributing to declining ADG during this period compared to the preceding period. Firstly, a decline in the feed value of grass silage relative to that of grazed grass is perhaps the most important reason for the reduction in ADG during the winter housing period. Typically, the nutritional value of silage varies greatly depending on the production process and the quality of the harvested sward, with poor grass management practices resulting in unpalatable silage with poor digestibility and reduced feed value (O'Kiely and Muck, 2014). Secondly, the transition from pasture to housing may result in heifers entering an increasingly competitive feeding environment. Thirdly, the feed conversion efficiency is lower in heifers of this age when compared to younger heifers (Bach et al., 2021).

During this period, a number ($n = 22$) of contract-and home-reared heifers experienced a loss in BW. Additionally, a considerable proportion of heifers on both farm types experienced marginal to no growth during this period (1.3% of heifers across farms grew less than 0.1 kg/day), indicating sub-optimal management practices on these farms. Given that previous heifer morbidity was not associated with the growth rate during this period (*vide infra*), it is likely that the reason for poor heifer growth was due to undernutrition and represents a wasted opportunity for some dairy farmers and contract- rearers to improve heifer growth rates to ensure heifers reach an adequate prebreeding BW for successful conception.

Average daily gain between V3-4

The ADG during this period corresponds to heifer growth during the second grazing period. Heifer ADG was greatest during this period when compared to all other rearing periods, and this may be explained by the transition from lower-quality grass silage diet during the housing period to high-quality grazed grass diet after turnout. A compensatory growth effect is also likely to have contributed to the increased heifer ADG during this period. The association between accelerated BW gain and increased feed efficiency following a period of undernutrition and reduced growth, such as feeding of poor quality silage during the housing period, is well documented in cattle (Hornick et al., 2000). A further cause of the increased ADG during this period is the contribution of foetal growth, particularly for heifers weighed towards the end of the fourth visit period, who were closest to calving. Contract-reared heifers achieved significantly greater growth rates than home-reared heifers during this period (0.069 kg/day).

Association between heifer morbidity and average daily gain

Several studies have reported associations between clinical disease events including pneumonia and diarrhoea during the rearing period and reduced heifer growth rates (Donovan et al., 1998; Windeyer et al., 2014; Abuelo et al., 2021). In particular, Donovan et al. (1998) reported an association between early calfhood disease and heifer growth rates between birth and 6 months of age and between 6 and 14 months of age. In the current study, we found no association between calf-hood disease events [pyrexia (temperature of $\geq$ 39.5 °C), pneumonia, diarrhoea or navel ill] and heifer growth rates across visit periods. While disease events occurring during the first autumn visit (V2) (including pyrexia, diarrhoea or pneumonia) did not affect heifer growth between V2 and the V3, a delayed effect of diarrhoea occurrence during V2 was associated with a reduced ADG between V3 and V4. Few studies have reported on the association between heifer morbidity and heifer growth rates beyond 14 months of age, making it difficult to draw direct comparisons between these and our study. It should also be considered that the morbidity data analysed in the current study were collected during one farm visit during each visit period, i.e. it was point-prevalence data and is not directly comparable with morbidity incidence data presented in other studies. The interaction between EBI maintenance sub-index and the occurrence of pyrexia at farm visit 3 was significant; however, there was no biological explanation for this interaction.

Conclusion

Overall, the average daily growth rates, in multiple rearing periods from birth to precalving, achieved by home-reared heifers were significantly greater than heifers on contract-rearing farms. While the absolute difference in daily growth rates of home- and contract-reared heifers was minimal, when considered in the context of the entire heifer-rearing period, these growth rate differences have the potential to negatively impact the future reproductive and milk production performance potential of heifers. While median heifer ADG exceeded minimum international target rates on both farm types for each period, there was a wide variation in ADG on both farm types. This indicates that many individual heifers failed to reach growth targets and may be of insufficient BW to reach puberty, conceive at 15 months and reach the desired AFC (24 months). In particular, heifer growth rates were poorest during the first winter housing period, indicating considerable scope for improvement in heifer-rearing management on both farm types during this time. These findings have implications for dairy heifer-rearing systems internationally.

Ethics approval

The study was conducted and approved by the Ethics Committee (TAEC) of Teagasc (TAEC177-2017, 2017), and procedure authorisation (AE19132/P075) was granted by the Health Products Regulatory Authority of Ireland (HPRA). The experiment was undertaken in accordance with the European Union (Protection of Animals Used for Scientific Purposes) Regulations 2012 (S.I. No. 543 of 2012).

Data and model availability statement

None of the data nor the models were deposited in an official repository. Data are available upon reasonable request.

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Declaration of interest

The authors declare that there are no conflicts of interest.

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