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Heifer Growth Effects on Milk Production, Days Open, Somatic Cell Count and Longevity in Norwegian Red Cows

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Abstract

With the constant genetic improvement of Norwegian Red Dairy cows, there is a need to investigate whether the management for optimal production has been updated accordingly. The aim of this study was to further look into the effect heifer growth has on parameters important for milk production traits, in addition to the potential relationship between growth and longevity. Information about growth and milk characteristics from 421 dairy cows from a field trial conducted on 30 Norwegian dairy farms were used to test the former. Additionally, data from 514 cows with growth information was used to test if growth affected longevity. Our models pointed towards milk yield being most strongly affected by daily growth rate between 10-15 months of age. Besides these results, we generally found the most influential effects of daily gain in the prepubertal stage, with significant effects on the protein percentage in milk, days open (DO) and somatic cell count (SCC). While we found positive linear effects on milk yield and protein percentage, DO and SCC effects were curvilinear effect, indicating an optimum of around 800 grams/day for prepubertal growth. Also for longevity, we found a positive linear effect of prepubertal growth implying that the probability of culling became increased. This occurred when either taking account of the culling reason or not in the analysis, the ones increasing the probability of culling the most being low production, inferior fertility and temperament. Based on these findings, we argue that it is beneficial to aim for a more moderate daily growth rate in the prepubertal time period.

1.0 Introduction

The Norwegian dairy production is, in large, organised cooperatively. This involves a large collective contribution by the dairy farmers to collect and share data across herds. Data collected from each farm is gathered and processed in the Norwegian Dairy Herd Recording System (NDHRS), which is owned by the cooperative TINE SA, and in which 97% of dairy producers in Norway are members of (TINE SA). Besides data recorded on a farm level, data from several other sources, such as slaughterhouses and breeding organizations is also gathered in NDHRS. This collection of information provides a solid basis for breeding efforts conducted by breeding organizations such as Geno, in addition to consultancy related to own production for members. It is also a good foundation for further research related to the dairy industry (TINE SA). In 2023, records from about 125,600 cows per year equivalent from just over 4000 herds were included in the annual settlement for NDHRS, with an average milk yield of 7,955 kg milk (Kukontrollen, 2023). Economic aspects of milk production are influenced by many factors and traits, and gaining a better understanding on how these interplay may improve the production efficiency and sustainability of production.

The most common breed for dairy production in Norway is the Norwegian Red (NR). It is a dual purpose, and is characterized by high milk production, produces a lot of meat, has good fertility and good health. Additionally, it calves easily and is very vigorous (Geno SA, 2023a). The NR is the result of continuous breeding effort to breed a cow that is best suited to the needs of Norwegian milk producers, and the breeding material has integrated Norwegian local breeds, as well as genetic material from mainly Nordic breeds, with characteristics that have matched the breeding goals of the NR throughout the ages.

The current breeding program for the NR is based on breeding values from one-step genomic selection, right from the first step of selection of bull and heifer calves, to the last step where elite bulls are selected. Genotyping is done with a SNP chip containing approximately 55,000 SNPs (Geno SA, 2023b). With genomic selection, the generation interval is shortened, selection intensity might become large if a large number of animals are genotyped, despite a not too high accuracy of breeding values, and this has boosted recent genetic progress (Geno SA, 2021).

Longevity is a trait of great complexity, with a large number of influencing factors. It has previously been documented that longevity in dairy cows has an impact on environment and sustainability (Clasen et al. (2024), and sustainability is an important topic in today's dairy production. For a farm to be sustainable, it is important to rear replacement heifers that achieve full lifetime potential in a manner of yield and profitability (Brickell et al., 2009). In Norway an average cow is kept only for 2.7 lactations (Kukontrollen, 2023). Environmentally, it would be preferable to keep the cows in production longer. Identifying factors which may have an impact on longevity is therefore important.

The aim of this study was to attempt to replicate the results on the curvilinear relationship between daily growth rate and first lactation milk yield (optimum around 830 gram per day between 10 and 15 months of age) in the paper by Storli et al. (2017) with an expanded dataset and across multiple lactations. Another aim was to study how heifer growth affects the milk contents, days open and somatic cell count, in first lactation, but also over the entire lifetime. The third objective was to estimate the effect of growth on longevity in dairy cows, when either accounting for recorded culling reasons or not.

2.0 Materials and methods

2.1 Data collection

The data set used for analyses, originates from a field trial carried out in 2012 to 2014 used in the paper by Storli et al. (2017).

In brief, data for growth in heifers born in 2011/2012 was gathered from 30 Norwegian herds. These herds were evenly distributed over three regions (respectively in mid, southwest and southeast Norway). Ten herds with either an average of either high (above 7,500 kg ECM /305 days) or low (under 6,500 kg ECM in/305 days) milk yield in the first lactation (five of each) from each region were chosen so that the sample should have a representative variation. The sampling criterias were as following; each herd had to have more than 30 cow per year equivalents, unchanged management of heifers from the years 2010-2012, freestall barns, a membership in the NDHRS, mainly production on Norwegian Red (NR) cows, and a willingness to participate in the trial from the farmers. In addition, it was required that heifers had a NR AI sire. Heifers born as twins were excluded from the data set. In total 11,066 heart girth measurements from 3,110 heifers were conducted. These measurements were done by eight different advisors from Tine SA, and the measurements were conducted by the same person within the same herd, with only one exception (where the new advisor was calibrated against the former before measuring). Heart girth measurements were converted to kg body weight as explained by Storli et al. (2017).

Storli et al. (2017) utilized data from 536 heifers with heart girth measurements to calculate their daily gain in grams/day for three time periods. These heifers had to have repeated measurements over a minimum of 300 days. The first measure had to be before the age of 275 days, while the last had to be after 575 days of age. These measures were used to calculate prepubertal growth rates between 5 and 10 months of age, between 10 and 15 months of age, and between 15 and 21 months of age. To examine the relationship between these growth rates and milk production, Storli et al. (2017) implemented a number of restrictions for animals with calculated daily gain. All heifers had to calve from October 2013 throughout October 2014. Additionally they had to have been artificially inseminated by a NR AI sire. Only heifers with one calf born were included. After edits, Storli et al. (2017) had 350 heifers with a total of 1,510 test day observations for milk yield in the first lactation.

Now, approximately 10 years later, possibly more of the 536 heifers with growth rate data in Storli et al (2017) would have obtained data not only for milk yield , but also for other milk production traits, fertility, health related traits and longevity and thus these data was the basis for our study. In addition to the growth data, pedigrees for the relevant animals were extracted from NDHRS in order to construct a relationship matrix and include genetic effect in the models. In total, the kinship between 3924 animals were included.

2.2 Lactation

2.2.1 First lactation 305-day milk characteristics (Model 1)

A total of five traits were available as the response variables.

The first was milk yield in kilograms for 305 days of lactation (kg 305 days). The second and third traits were average protein percent in milk (%) and average fat percent in milk (%) for the same 305 days, respectively. Additionally, days open, which is defined as number of days between calving and the following conception (number of days) was available and can be considered a fertility variable (Lucy, 2019). Thus, days open was considered as a separate response variable, for which the natural logarithm was used to achieve more normal distribution of data, but also included as a fixed effect in the models for the other response variables. Lastly, the natural logarithm of the average somatic cell count in milk (SCC) was also used as a response variable in the models.

A priori to analysis, some of the 536 animals in the data with growth data were excluded. These were animals that in the current sampling of data from NDHRS were a crossbreed or a breed other than NR. In addition, calves sold between herds during the period in which heart girth measurements were carried out, as well as pregnant heifers sold before first calving, were also excluded from the final dataset. Furthermore, only animals with observations for milk variables were included, imposing that a whole herd was excluded due to missing milk data.

A total of 421 animals had observations for milk characteristics in the first lactation. *Figure 1* shows a visual representation of the number of animals with growth rates, used by Storli et al. (2017) and in our analysis. Out of these 421 animals, 65 (15.4%) of the cows did not complete 305 days lactation, and therefore had calculated values for the traits. Whether lactations were shortened or not was known and considered as a fixed effect (*BL*) in succeeding analyses.

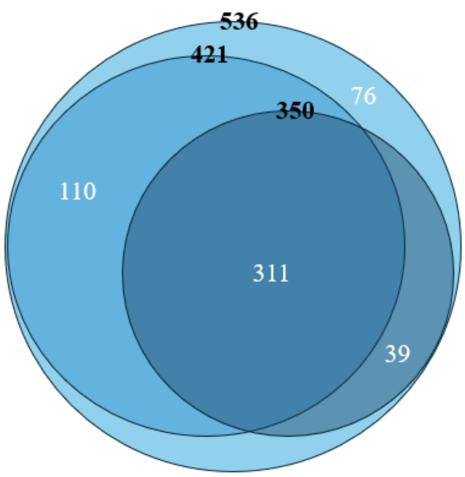

Figure 1:Visualization of number of animals with estimated growth rates (n=536), used in milk models in this paper (n=421) and used in the first lactation yield study of Storli et al. (2017) (n=350).

For the analysis of data in the first lactation, the following linear animal model was used (Model 1):

$$Y_{ijklm} = \mu + S_i + AFC_j + BL_k + \beta_1 \cdot X + \beta_2 \cdot X^2 + \beta_3 \cdot DO + \beta_4 \cdot DO^2 + herd_l + Cow_m + e_{ijklm},$$

where Y_{ijklm} is an observation for one of the five previously defined production traits in the first lactation, S_i is the fixed effect of *i*th calving season [i = 1, …, 4; March to May (n = 91), June to August (n = 134), September to November (n = 105), December to February (n = 91)]; AFC_j is the fixed effect of the *j*th age class of the first calving [j = 1, …, 5; ≤23 (n = 121), 24 (n = 78), 25 (n = 66), 26 (n = 55), ≥27 (n = 101) months old]; BL_k is the fixed effect of the *k*th calculation class for milk data [k = 1, 2; calculated (n = 65), not calculated (n = 356)]; β_1 is the fixed linear regression of the growth variables (5-10 months, 10-15 months or 15-21 months); β_2 is the effect of the squared growth variable, β_3 is the fixed linear regression of days open, an β_4 is the effect of squared days open variable, $herd_m$ is the random effects of the *l*th herd [~ N (0, $I\sigma^2_{herd}$)] and and Cow_m is the random effect of the *m*th cow [~ N (0, $A\sigma^2_{cow}$)];, with A being the 3924 x 3924 relationship matrix for cows, and I an 29 x 29 identity matrix for herd, and finally, e_{ijklm} is the random error associated with each observation [~ N (0, $I\sigma^2_e$)].

2.2.2 All lactations milk characteristics (Model 2)

A second model was used utilising information across lactations. For animals sold out of the herd, only lactations completed within the original herd were included. This meant that at least 305 days had to pass between date of calving and date sold for the respective lactation to be included. 421 individuals with a total of 1002 observations distributed across five lactations were included in the model. A total of 239 lactations were calculated.

For the analysis of the traits across lactation, the following linear animal repeatability model was used (Model 2):

$$Y_{ijklmno} = \mu + S_i + AFC_j + BL_k + Lac_l + \beta_1 \cdot X + \beta_2 \cdot X^2 + \beta_3 \cdot DO + \beta_4 \cdot DO^2 + herdyear_m + Cow_n + PE_o + e_{ijklmno},$$

where model 1 extended with the Lac_l (l = 1, …, 5) and PE_o, where Lac_l is the fixed effect of the lth parity number of the cow, PE_o is the random repeated effect of the cow's measurements [~ N (0, $I\sigma^2_{PE}$)], with I being an 421 x 421 identity matrix, and $e_{ijklmno}$ is the random error associated with each observation [~ N (0, $I\sigma^2_e$)].

2.3 Longevity

2.3.1 Longevity model (Model 3)

For the analysis of longevity, some of the 536 animals in the data set had to be excluded. Animals sold between herds were excluded so that all animals lived in the same environment throughout life. As with the models for milk characteristics, animals that were of a crossbreed or a breed other than NR were excluded. One animal who was still alive was also excluded. A total of 514 animals were included in the model for longevity. Out of these 412 of these animals were also included in our data used in the lactation models (*Models 1 and 2*), this is visualized in *Figure 2*.

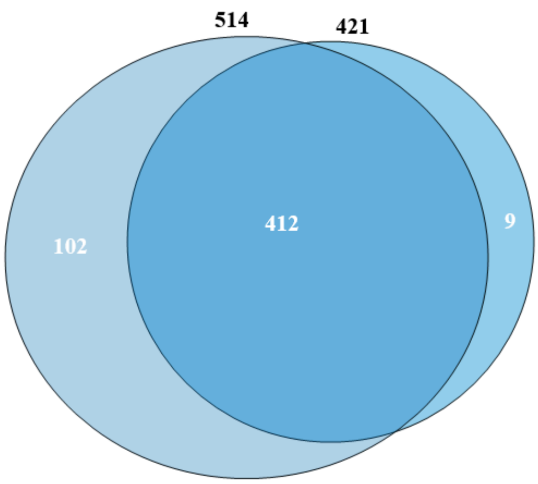

Figure 2: Visualization of number of animals with used in milk models in this paper (n=421) and used in the models for longevity (n=514).

To calculate longevity, ten time periods based on time of culling (*Table 2*) were made, assigning one phenotype, culled or not, scored 0 or 1 for each period. All animals that were weighed were later assumed to be bred when they reached sexual maturity, implying that they all received a value of zero at time period 0 (t_0). At the second stage (t_1), the animals who had their first calf were given the value of zero, while the animals culled after breeding, but never calved, were given the value one. The animals who previously received the value zero at t_1, moved on the next stage (t_2). Animals who then got their second calf received yet another value of zero, while animals culled after their first calf, and therefore never had a second calf received the value of one. This pattern continued until time period ten (t_9) where no cows had their 9th calf, and thereby all animals had a number of records. As the animals did not progress to the next time period after culling (when given a value of one at the time period in which they were culled), the last record for all animals thereby ended with a value of 1, as seen in *Table 2*.

Moreover, each observation for every individual was assigned a value to describe at which stage the animal was culled. This was based on how many time periods (t_0-t_9) the animal lived through, including the stage where culling occurred.

Table 2: Number of animals per time period. When given the value of one, the animals were culled and did not move on to the next time period.

Time period	Life event	N	Value	Stage
t_0	Growth measured and assumed bred	514	0	1
t_1	Calved 1st calf	484	0	2
	Not calved 1st calf	30	1	
t_2	Calved 2nd calf	333	0	3
	Not calved 2nd calf	151	1	
t_3	Calved 3rd calf	200	0	4
	Not calved 3rd calf	133	1	
t_4	Calved 4th calf	108	0	5
	Not calved 4th calf	92	1	
t_5	Calved 5th calf	49	0	6
	Not calved 5th calf	59	1	
t_6	Calved 6th calf	22	0	7
	Not calved 6th calf	27	1	
t_7	Calved 7th calf	5	0	8
	Not calved 7th calf	17	1	
t_8	Calved 8th calf	2	0	9
	Not calved 8th calf	3	1	
t_9	Calved 9th calf	0	0	10
	Not calved 9th calf	3	1	

Longevity was analysed with the following models for three growth variables (Model 3):

(a) $Y_i = \mu + \beta_1 \cdot X + A_i + e_i$,

(b) $Y_i = \mu + \beta_2 \cdot X^2 + A_i + e_i$,

where Y_i is one observation for the binary trait of the lifespan of an animal, β_1 is the fixed linear regression of the growth variables (5-10 months, 10-15 months or 15-21 months); β_2 is the effect of the squared given growth variable, A_i is the fixed effect of the *i*th stage of culling of the cow [$i = 1, \ldots, 10$], and e_i is the random error associated with each observation [$\sim N(0, I\sigma^2_e)$].

2.3.2 Longevity model with culling effect (Model 4)

Finally, the longevity model (*Model 3*) was expanded with a fixed effect of the cause of culling, as reported by the respective farmers in NDHRS. In order to achieve a sufficient number of observations per fixed effect class, culling reasons were grouped in superior category classes, as shown in *Table 4*.

Table 4: Superior culling classes absorbing individual culling causes, with number of observations and percentages per class.

Culling group	Category	Culling causes	n	%
1	Udder	Big teats Small teats Other udder problems Poor foreteat position Poor fore udder balance Poor rear teat position Poor rear udder balance Poor udder attachment Poor udder quality Slow milking speed	55	10.7
2	Health	Pneumonia Vaginal prolapse Other Diseases	15	2.9
3	Milk	Poor milk production	93	18.1
4	Fertility	Low Fertility Bypass Miscarriage Poor heat Other fertility cause	89	17.3
5	Other cause	Accident in barn Other animal cause Other cause of slaughter Fallen stock Unfit other cause	99	19.3
6	Temperament	Poor temperament Sucking	25	4.9
7	Management	Old age Part of operation	12	2.3
8	Exterior	Arthritis Bone claw Corkscrew claw Foot and leg problems Poor claw heath Poor structural soundness Teat trampling	55	10.7
9	Mastitis	Mastitis High somatic cell count	71	13.8

For the analysis of the second longevity model, the following models was used for the three growth variables (Model 4):

(a) $Y_{ij} = \mu + \beta_1 \cdot X + A_i + Cu_j + e_{ijk}$,

(b) $Y_{ij} = \mu + \beta_2 \cdot X^2 + A_i + Cu_j + e_{ijk}$,

where the variable Cu_j ($j = 1, \ldots, 9$) is the fixed effect of the jth culling reason of the animal.

Studentized residuals were used for outlier detection in both model 1 and 2. No extreme observations were found, but lead to days open, when a response variable, being transformed and normalised by taking the natural logarithm.

Proprietary analysis was done by SAS software (SAS Institute Inc., Cary, NC, USA), while all statistical models were run with the R-package ASReml (v4.2.0.302; the VSNi Team 2023). For the construction of the relationship matrices, the R-Package pedigreemm was used (v.0.3-4; Bates et al. 2023).

3.0 Results

3.1 First lactation

Table 5 gives the relevant results for days open, milk yield (305 day lactation), protein percent, fat percent and SCC as response variables in the model for the first lactation. The model was run with backward elimination of the squared variables (growth rates and days open) with a $P > 0.1$.

Table 5: F-statistics and their corresponding p-value for the fixed effects in Model 1.

		F (P-value)						
Growth period	Response variable	S	AFC	BL	X	X^2	DO	DO^2
5-10	Days open[1]	1.57 (0.20)	1.21 (0.305)	15.86 (<0.001)	8.43 (0.004)	8.28 (0.004)	NE[6]	NE[6]
	Milk yield 305 days[2]	2.83 (0.039)	11.58 (0.000)	62.85 (0.000)	4.56 (0.033)	NS[7]	20.53 (<0.001)	NS[7]
	Protein %[3]	1.81 (0.145)	1.72 (0.145)	13.24 (<0.001)	5.14 (0.024)	NS[7]	4.96 (0.026)	NS[7]
	Fat %[4]	2.21 (0.086)	0.50 (0.733)	17.49 (<0.001)	0.27 (0.604)	NS[7]	2.91 (0.090)	NS[7]
	SCC[5]	0.53 (0.659)	1.19 (0.317)	2.88 (0.091)	10.99 (0.001)	12.10 (<0.001)	NS[7]	NS[7]
10-15	Days open[1]	1.66 (0.176)	1.49 (0.205)	16.30 (<0.001)	0.20 (0.654)	NS[7]	NE[6]	NE[6]
	Milk yield 305 days[2]	3.51 (0.015)	12.56 (0.000)	60.53 (0.000)	14.66 (<0.001)	NS[7]	22.44 (<0.001)	NS[7]
	Protein %[3]	1.58 (0.194)	11.79 (0.130)	14.41 (<0.001)	1.68 (0.196)	NS[7]	4.91 (0.027)	NS[7]
	Fat %[4]	2.11 (0.098)	0.49 (0.745)	17.98 (<0.001)	0.24 (0.624)	NS[7]	2.87 (0.091)	NS[7]
	SCC[5]	0.20 (0.900)	0.83 (0.508)	3.95 (0.047)	7.13 (0.008)	NS[7]	NS[7]	NS[7]
15-21	Days open[1]	1.60 (0.190)	1.51 (0.199)	16.06 (<0.001)	0.09 (0.766)	NS[7]	NE[6]	NE[6]
	Milk yield 305 days[2]	3.01 (0.030)	11.05 (0.000)	57.41 (0.000)	10.94 (0.001)	NS[7]	22.27 (<0.001)	NS[7]
	Protein %[3]	1.78 (0.150)	1.94 (0.102)	14.11 (<0.001)	0.00 (0.944)	NS[7]	5.10 (0.025)	NS[7]
	Fat %[4]	2.21 (0.087)	0.48 (0.753)	17.84 (<0.001)	0.05 (0.826)	NS[7]	2.90 (0.089)	NS[7]
	SCC[5]	0.15 (0.929)	1.07 (0.371)	4.16 (0.042)	4.15 (0.043)	NS[7]	NS[7]	NS[7]

[1] Models with ln(Days open) as response variable had σ^2_{herd} = 0.0088-0.0136 with std.error of 0.007-0.008, σ^2_{cow}= <0.000001-0.0008 with std.error of 0.015, σ^2_{e} = 0.1885-1.903 with std. error of 0.0198-0.020.

[2] Models with milk yield 305 days as response variable had σ^2_{herd} = 917948-990942 with std.error of 277203-298855, σ^2_{cow} = 220724-291548 with std.error of 167696-191770, σ^2_{e} = 936129-1023945 with std. error of 165196-179484.

[3] Models with protein % as response variable had σ^2_{herd} = 0.0042-0.0044 with std.error of 0.0018-0.0019, σ^2_{cow} = 0.0047-0.0054 with std.error of 0.0037-0.0054, σ^2_{e} = 0.0257-0.0267 with std.error of 0.0040.

[4] Models with fat % as response variable had σ^2_{herd} = 0.0221-0.0227 with std.error of 0.0087-0.0088, σ^2_{cow} = 0.0223-0.0228 with std.error of 0.0190-0.0191, σ^2_{e}= 0.1043-0.1047 with std.error of 0.0184-0.0185.

[5] Models with ln(SCC) as response variable had σ^2_{herd}= 0.0454-0.0509 with std.error of 0.0261-0.0279, σ^2_{cow}= <0.000001-0.0040 with std.error of 0.0464, σ^2_{e}= 0.6785-0.6960 with std. error of 0.0654-0.0667.

[6]NE = Not estimated, i.e. not included in the model as a fixed effect since it was a response variable.

[7]NS = Not significant (p > 0.1).

The results in Table 5 show that daily gain in the prepubertal period (5-10 months) significantly (P > 0.033) affected all the response variables except for fat percent. The effects were, as shown in Table 6, linearly positive for milk yield and protein percent, but curvilinear for both days open and SCC. This means that when daily gain in the prepubertal stage increases, so does milk yield and protein percent, while an optimum is indicated for days open and cell count.

Days open was also found significant for milk yield, protein percent and fat percent (on a 10% level), and the regression coefficient (Table 6) was positive for milk yield, but negative for protein percent and fat percent. This means that an increase in days open leads to an increase in milk yield, and a decrease in protein percent and fat percent.

Between 10 and 15 months, we again see that daily gain has a significant effect on milk yield and SCC (Table 5). The effects are positive (Table 6), meaning that when the daily gain increases, so does milk yield and SCC. As in the prepubertal stage, days open has a positive significant effect on milk yield and a negative significant effect on protein percent and fat percent. In large, the same results was obtained for the growth rate between 15 and 21 months as in the former period, between 10 and 15 months.

Whether lactation yields were calculated or not, BL had a significant effect ($P < 0.1$) on all the response variables. Age at first calving (AFC) has a significant effect on milk yield, while Season significantly affected both milk yield and fat percent ($P < 0.1$).

Table 6. First- and second-order regression coefficients of individual daily gain (β_1 and β_2) and days open (β_3 and β_4) in Model 1.

Growth period	Trait	β_1	β_2	β_3	β_4
5-10	Days open	-0.010276	0.000006	NE	NE
	Milk yield 305 days	1.891435	NS	5.354108	NS
	Protein %	0.000295	NS	-0.000488	NS
	Fat %	0.000138	NS	-0.000634	NS
	SCC	-0.022769	0.000015	NS	NS
10-15	Days open	-0.000157	NS	NE	NE
	Milk yield 305 days	3.790903	NS	5.522212	NS
	Protein %	0.000191	NS	-0.000409	NS
	Fat %	0.000147	NS	-0.000630	NS
	SCC	0.001779	NS	0.000635	NS
15-21	Days open	-0.000063	NS	NE	NE
	Milk yield 305 days	2.034577	NS	5.520650	NS
	Protein %	-0.000006	NS	-0.000417	NS
	Fat %	0.000040	NS	-0.000634	NS
	SCC	0.000823	NS	0.000600	NS

In Figure 3, plotting days open versus the growth rate in the prepubertal period, our results point towards an optimal prepubertal daily gain of approximately 800 grams.

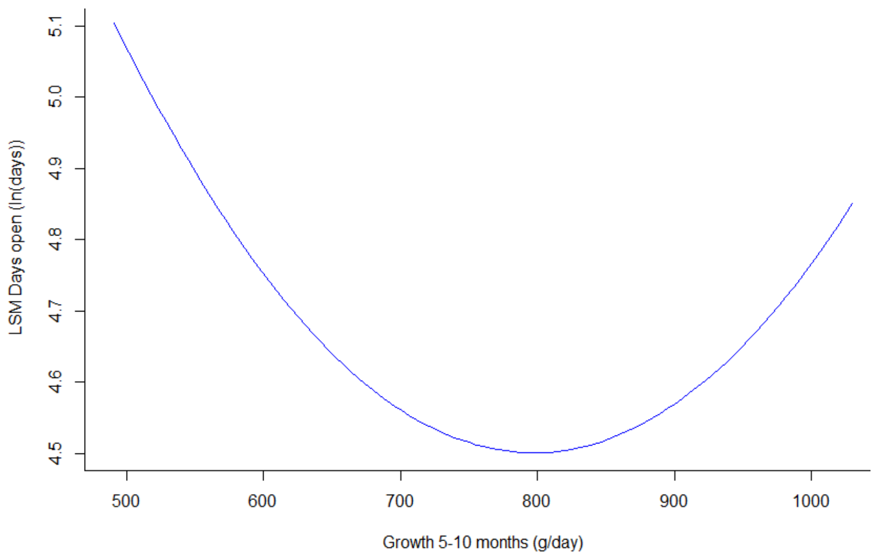

Figure 3: Least square means of log(days open) in 1.lactation for prepubertal growth between 5 and 10 months of age when the individual daily gain was between 491 g/day (min) and 1030 g/day (max). The curve illustrates the following equation: $y = 8.596144 - 0.010276x + 0.000006x^2$ *(P = 0.004 for both).*

Similarly, in Figure 4, our results point towards an optimal prepubertal daily gain of approximately 760 grams for SCC in first lactation.

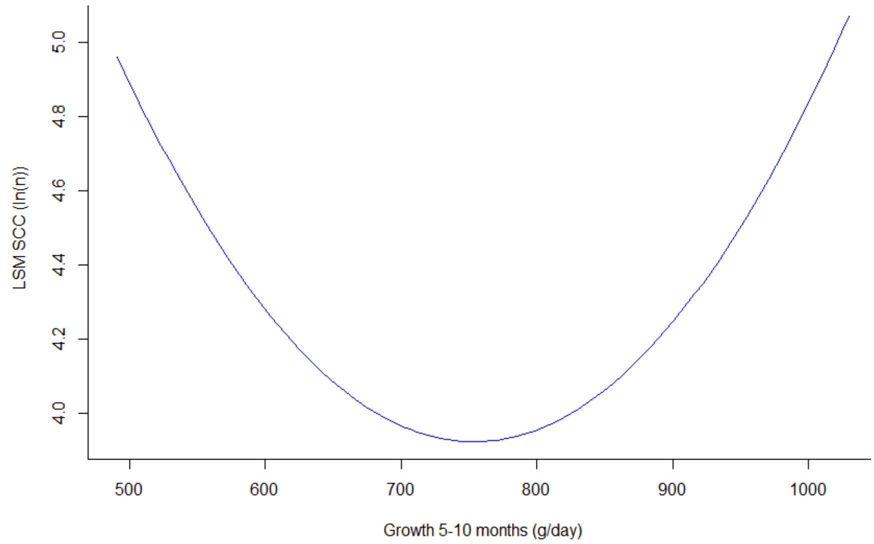

Figure 4: Least square means of SCC in milk in 1.lactation for prepubertal growth between 5 and 10 months of age when the individual daily gain was between 491 g/day (min) and 1030 g/day (max). The curve illustrates the following equation: $y = 12.47251 - 0.022684x + 0.000015x^2$ *(P = 0.001 and < 0.001, respectively).*

Regarding both milk yield and protein percentage, the relationship to growth rate was positive, meaning that an increase in daily gain will lead to an increase in both milk yield and the protein fraction in milk for the first lactation.

3.2 All lactations

Table 7 gives the relevant results for the five across all lactations. This model was also run with backward selection of the squared effects (growth period and days open) to find significant effects of the fixed effects and to see if we could find curved lines for optimum values.

Table 7: F-statistics and their corresponding p-value for the fixed effects in Model 2.

		F (P-value)							
Growth period	Trait	S	AFC	BL	Lac	X	X^2	DO	DO^2
5-10	Days open[1]	2.94 (0.032)	1.06 (0.376)	50.66 (0.000)	1.12 (0.345)	17.94 (<0.001)	17.54 (<0.001)	NE[6]	NE[6]
	Milk yield 305 days[2]	2.82 (0.004)	10.31 (0.000)	120.10 (0.000)	10.83 (0.000)	4.38 (0.037)	NS[7]	9.99 (0.002)	NS[7]
	Protein %[3]	1.42 (0.235)	1.52 (0.198)	8.45 (0.004)	6.22 (<0.001)	2.94 (0.087)	NS[7]	NS	NS[7]
	Fat %[4]	0.19 (0.313)	0.23 (0.922)	5.84 (0.016)	1.39 (0.236)	0.77 (0.381)	NS[7]	NS[7]	NS[7]
	SCC[5]	0.91 (0.435)	0.81 (0.521)	29.90 (0.000)	14.84 (0.000)	7.36 (0.007)	8.29 (0.004)	4.59 (0.032)	6.31 (0.012)
10-15	Days open[1]	3.18 (0.024)	1.25 (0.287)	52.21 (0.000)	0.11 (0.360)	0.00 (0.966)	NS[7]	NE[6]	NE[6]
	Milk yield 305 days[2]	3.05 (0.028)	10.35 (0.000)	108.9 (0.000)	10.84 (0.000)	8.35 (0.004)	NS[7]	10.48 (0.001)	NS[7]
	Protein %[2]	1.24 (0.293)	1.62 (0.166)	9.09 (0.003)	6.26 (<0.001)	1.32 (0.251)	NS[7]	NS[7]	NS[7]
	Fat %[3]	1.03 (0.379)	0.24 (0.917)	6.16 (0.013)	1.44 (0.221)	2.18 (0.141)	NS[7]	NS[7]	NS[7]
	SCC[4]	0.46 (0.707)	0.67 (0.615)	31.76 (0.000)	14.05 (0.000)	10.48 (0.001)	NS[7]	3.88 (0.049)	5.82 (0.016)
15-21	Days open[1]	3.22 (0.022)	1.25 (0.287)	52.32 (0.000)	0.10 (0.356)	0.25 (0.619)	NS[7]	NE[6]	NE[6]
	Milk yield 305 days[2]	2.75 (0.042)	9.64 (0.000)	118.1 (0.000)	10.81 (0.000)	4.36 (0.037)	NS[7]	10.56 (0.001)	NS
	Protein %[3]	1.20 (0.315)	1.70 (0.147)	9.00 (0.003)	6.30 <(0.001)	0.00 (0.921)	NS[7]	NS[7]	NS[7]
	Fat %[4]	0.01 (0.385)	0.27 (0.900)	6.32 (0.012)	1.45 (0.217)	1.35 (0.247)	NS[7]	NS[7]	NS[7]
	SCC[5]	0.53 (0.662)	0.85 (0.493)	32.37 (0.000)	14.02 (0.000)	6.57 (0.011)	NS[7]	3.94 (0.047)	5.86 (0.016)

[1] Models with ln(Days open) as response variable had $\sigma^2_{herdyear}$ = 0.0058-0.0102 with std.error of 0.0043 - 0.0051, σ^2_{AE} = 0.0268 - 0.0298 with std.error of 0.0084-0.0087, σ^2_{cow} = 0.00000008-0.0000006 with std.error of NA, and σ^2_{e} = 0.1849 - 0.1868 with std.error of 0.0110 - 0.0111.

[2] Models with milk yield 305 days as response variable had $\sigma^2_{herdyear}$ = 792567 - 851286 with std.error of 140343 - 147759, σ^2_{AE} = 388173-431937 with std.error of 163083-166622, σ^2_{cow} = 287079-317501 with std.error of 171919-179443 nad σ^2_{e} = 862983-864291 with std.error of 55113-55218.

[3] Models with protein % as response variable had $\sigma^2_{herdyear}$ = 0.0016 with std.error of 0.0006, σ^2_{AE} = 0.0154 - 0.0161 with std.error of 0.0044-0.0045, σ^2_{cow} = 0.0080 - 0.0086 with std.error of 0.0047 - 0.0049 and σ^2_{e} = 0.0122 with std.error of 0.0008.

[4] Models with fat % as response variable had $\sigma^2_{herdyear}$ = 0.0219 - 0.0222 with std.error of 0.0061 - 0.0062 and σ^2_{AE} = 0.0394-0.0429 with std.error of 0.0214-0.0222, σ^2_{cow} = 0.0372 - 0.0413 with std.error of 0.0235 - 0.0248, σ^2_{e} = 0.0989 - 0.0991 with std. error of 0.0062.

[5] Models with ln(SCC) as response variable had $\sigma^2_{herdyear}$ = 0.0401 - 0.0439 with std.error of 0.0169 - 0.0174 and σ^2_{AE} = 0.2670-0.2692 with std.error of 0.0381 - 0.0384, σ^2_{cow} = 0.00000005 - 0.0000002 with std.error of NA, σ^2_{e} = 0.4818 - 0.4840 with std. error of 0.0299 - 0.0300.

[6]NE = Not estimated, i.e. not included in model as a fixed effect since it was a response variable.

[7]NS = Not significant ($p > 0.1$).

In main, the same results are seen across lactations as in the first. Daily gain in the prepubertal stage has a significant effect ($P < 0.1$) on all response variables except fat percentage, but at later stages, daily gain only has significant effects on milk yield and SCC. As before, the effects on milk yield and protein percent are positive (Table 8), while they were curvilinear for days open and SCC. More over, days open only had significant effects on milk yield and SCC, through all stages of growth. Whether lactations were prolonged or not was again significant ($P< 0.02$) for all response variables. AFC was only significant for milk yield, and Season was significant for days open and milk yield.

Table 8. First- and second-order regression coefficients of individual daily gain (β_1 and β_2) and days open (β_3 and β_4) in Model 2.

Growth period	Trait	β_1	β_2	β_3	β_4
5-10	Days open	-1.029694	0.000654	NE	NE
	Milk yield 305 days	0.712595	NS	2.681534	NS
	Protein %	0.000187	NS	NS	NS
	Fat %	0.000211	NS	NS	NS
	SCC	-0.015441	0.000010	-0.003802	0.000015
10-15	Days open	0.000011	NS	NE	NE
	Milk yield 305 days	2.579907	NS	2.350893	NS
	Protein %	0.000148	NS	NS	NS
	Fat %	0.000410	NS	NS	NS
	SCC	0.001729	NS	-0.003492	0.000014
15-21	Days open	0.000075	NS	NE	NE
	Milk yield 305 days	1.134055	NS	2.361654	NS
	Protein %	0.000008	NS	NS	NS
	Fat %	0.000193	NS	NS	NS
	SCC	0.000819	NS	-0.003524	0.000014

In Figure 5, the curvilinearity between days open and prepubertal growth rate point towards an optimal daily prepubertal gain of approximately 790 grams.

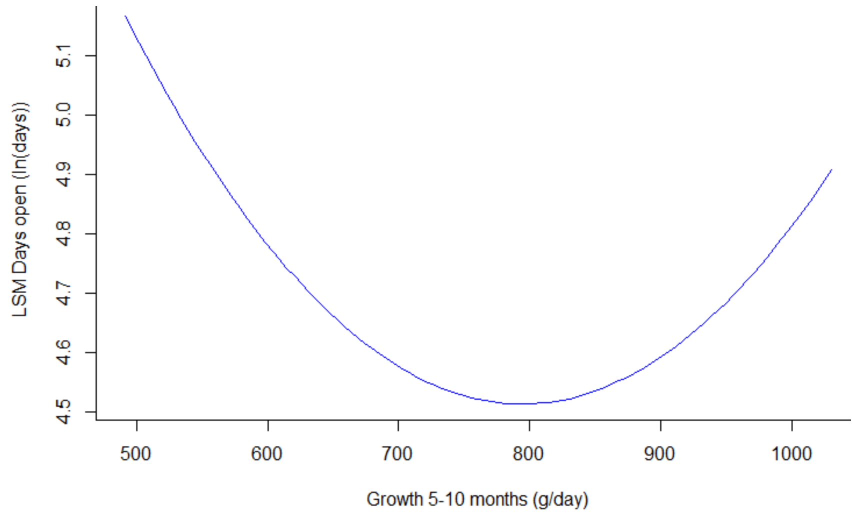

Figure 5: Least square means of log(days open) across all lactations for prepubertal growth between 5 and 10 months of age when the individual daily gain was between 491 g/day (min) and 1030 g/day (max). The curve illustrates the following equation: $y = 9.000374 - 0.011298x + 0.000007x^2$ (P = < 0.001 for both).

Similar optimability between prepubertal growth rate and SCC, Figure 6, point towards a slightly lower optimality of 740 grams.

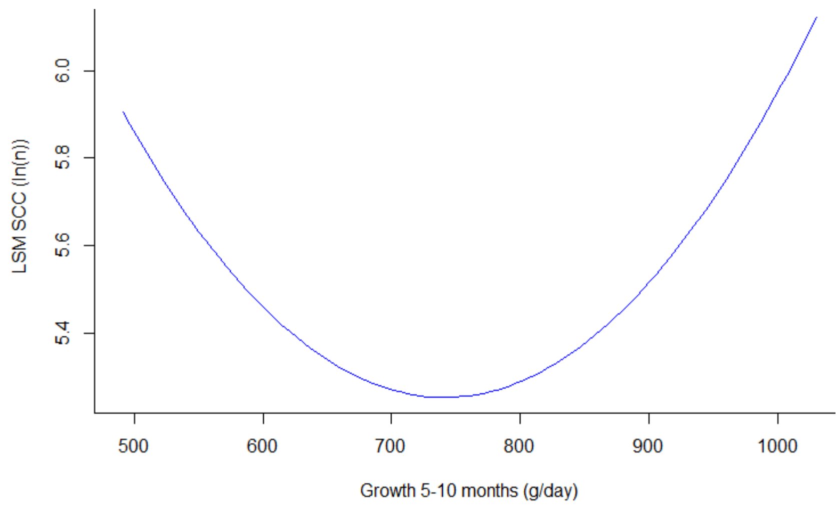

Figure 6: Least square means of SCC in milk across all lactations for prepubertal growth between 5 and 10 months of age when the individual daily gain was between 491 g/day (min) and 1030 g/day (max).The curve illustrates the following equation: $y = 10.9748 - 0.015441x + 0.00001x^2$ (P = 0.007 and 0.004, respectively).

Finally, across all lactations, again increasing daily gain at every growth stage will lead to increasing milk yield for all lactations.

3.3 Longevity model

Table 9 and 10 gives the relevant results for lifespan as response variable when either of the growth rates were included as first or second order term. The second degree variable (Table 10) was slightly more significant than the first degree variable (Table 9). Daily gain was, however, only significant in the period 5 to 10 months, with a positive regression coefficient on lifespan. This means that if the daily gain increases, so does the animals' probability of being culled. Moreover, stage when culled was highly significant overall.

Table 9: F-statistics, p-values, and associated regression coefficients (β_1) for individual daily gain in Model 3a.

	F (P-value)		
Growth period	X	β_1	Stage
5-10	7.60 (0.006)	0.000290	62.21 (0.000)
10-15	0.25 (0.620)	0.000061	60.87 (0.000)
15-21	2.27 (0.132)	-0.000113	61.21 (0.000)

$\sigma^2_{herdyear}$= 0.0087-0.0098 with std.error of 0.0025-0.0026

σ^2_e = 0.1293-0.1294 with std.error of 0.0041

Table 10: F-statistics and their corresponding p-value for the fixed effects, and regression coefficients (β_2) for squared individual daily gain in Model 3b.

	F (P-value)		
Growth period	X^2	β_2	Age
5-10	7.80 (0.005)	0.0000002	62.24 (0.005)
10-15	0.30 (0.587)	0.00000004	60.87 (0.000)
15-21	1.98 (0.160)	-0.00000007	61.15 (0.000)

$\sigma^2_{herdyear}$= 0.0087-0.0098 with std.error of 0.0025-0.0026

σ^2_e = 0.1293-0.1294 with std.error of 0.0041

3.4 Longevity model accounting for reported culling cause

Table 11 and 12 gives the relevant results for longevity as a response variable. As in the models not accounting for the culling cause (Model 3a and 3b), daily gain was only significant in the period 5 to 10 months, with a positive regression coefficient on longevity, meaning that longevity decreases with increased prepubertal growth rate. Moreover, age and culling reason were highly significant (P < 0.01) overall.

Table 11: F-statistics and their corresponding p-value for the fixed effects, and regression coefficients (β_1) for individual daily gain in Model 4a.

	F (P-value)			
Growth period	X	β_1	Age	Culling
5-10	6.04 (0.014)	0.000256	70.57 (0.000)	10.69 (0.000)
10-15	1.20 (0.273)	0.000134	69.48 (0.000)	11.00 (0.000)
15-21	0.26 (0.607)	-0.000039	69.4 (0.000)	10.62 (0.000)

$\sigma^2_{herdyear}$= 0.0083-0.009 with std.error of 0.0024-0.0025

σ^2_e = 0.1250-0.1251 with std.error of 0.0039

Table 12: F-statistics and their corresponding p-value for the fixed effects, and regression coefficients (β_2) for squared individual daily gain in Model 4b.

	F (P-value)			
Growth period	X^2	β_2	Age	Culling
5-10	6.16 (0.013)	0.0000002	70.59 (0.000)	10.68 (0.000)
10-15	1.28 (0.259)	0.00000009	69.48 (0.000)	11.01 (0.000)
15-21	0.18 (0.673)	-0.00000002	69.37 (0.000)	10.65 (0.000)

$\sigma^2_{herdyear}$= 0.0083-0.009 with std.error of 0.0024-0.0025

σ^2_e = 0.1250-0.1251 with std.error of 0.0039

Table 13 presents the effect of the culling causes as culling probabilities. Group 3 (poor milk production), 4 (fertility causes) and 6 (temperament causes) has the relatively (relative to group 1) most expressed probabilities of being culled give relatively high probability of being culled, with 11.36%, 15.77% and 16.02%, respectively.

Table 13: Solutions for culling causes with standard errors in Model 4b.

		solution	std. error
Culling group	1	0.0000	NA
	2	0.0586	0.0504
	3	0.1136	0.0301
	4	0.1577	0.0307
	5	-0.0133	0.0295
	6	0.1602	0.0455
	7	-0.1287	0.0491
	8	0.0330	0.0324
	9	-0.0133	0.0299

4.0 Discussion

4.1 Milk characteristics

In correspondence with Storli et al. (2017) and Salte et al. (2020), our results confirm the largest strong effect of daily gain on milk yield when the heifers are 10-15 months. Besides these results, we generally find the most influential effects of daily gain in the prepubertal stage.

Puberty in dairy heifers normally begins at an average body weight of between 250-280 kg. This usually happens between 9-11 months of age, but can vary greatly (Sejrsen, 1994). Foldager et al. (1988) found in their experiments that puberty could occur as early as 5 to 6 months and as late as 18 to 20 months of age. Weight could also vary, but very few reached puberty under 200 kg and over 300 kg. Nutrition is an important factor when it comes to age at occurring puberty (Schillo et al. 1992). This was illustrated when Foldager et al. (1988) managed to lower the mean age of reaching puberty from 16.6 to 8.4 months by increasing the daily gain from 400 to 850 g/d, meaning that the heifers reached a higher body weight earlier. Sejrsen et al. (1982) found that feeding levels causing daily gains higher than 600-700 g in heifers had a negative effect on mammary development and that high feeding levels were negative for the mammary glands from an early age. Sejrsen (1994) proposed a theory about growth hormone having an effect on mammary development via insulin-like growth factor 1 (IGF-1) for prepubertal heifers. However, Salte et al. (2020) found in their study that lowering AFC to 22 months did not cause over-conditioning at calving or impair the milk yield over 3 lactations as long as the animal had enough estrous cycles (6-7) for the mammary gland to have a proper development before insemination. These results indicate that higher daily gain will cause the animal to reach puberty earlier and thus will be able to have a lower calving age without reducing the milk yield.

We find that prepubertal growth has a significant effect on days open, with an optimum of about 800 g/day for the lowest number of days open. Daily gain in and after puberty does not seem to have a significant effect on days open. Days open is a trait measuring the number of days between calving and the subsequent conception. After calving, the cow typically enters a state of negative energy balance (NEB) as the energy required for milk production exceeds the energy intake the cow is able to consume (e.g., Baumgard et al., 2006). The negative effect of NEB on fertility traits is well documented (Wathes et al., (2007), Fenwick et al., (2008), Butler (2005)). IGF-1 has been identified as an important factor in the relationship between NEB and reproduction in dairy cows, so that the blood concentration level of IGF-1 is reduced with an increased severity of NEB in the early postpartum phase (Song et al. 2021, Fenwick et al. 2008). Beam & Butler (1998), found that a low level of circulating IGF-1 is associated with poor reproduction. Falkenberg et al. (2008) also found an association between the blood concentration of IGF-1 and reproduction. As the time period between calving and conception is a fertility trait dependent on energy balance, it may be reasonable to think that days open can be looked at in light of NEB. Since growth rate had an effect on days open, and days open is partly determined by NED, we estimated the effect of the growth rate when adjusted for days open, by including days open in the statistical model for the five lactation traits.

Our analysis used data over 305 days of lactation instead of test-day data that was used in the study by Storli et al. (2017), and we found, generally, that an increased growth rate increased milk production, contrary to Storli et al. (2017) who found an optimum for postpubertal growth. One reason for not finding a curvilinear relationship between milk yield and daily gain as found by Storli et al. (2017), may be that we looked at 305 day lactation (whether measured or estimated), meaning that animals early culled and utilised by Storli et al. (2017), were not included in the 305 data. But as seen in *Figure 1,* 39 animals used in the study by Storli et al.

(2017), were not included in our data. This might have had an effect on our estimate in direction of an advantage of a steadily increasing growth rate (not a curvilinearity). Moreover, our model did account for DO, while Storli et al. (2017) did not. Since DO is related to NEB and IGF1, and growth rate is also related to IGF1, the two variables growth rate and DO will be colinear, meaning that including DO in the model might have caused the result. New tools, e.g. gene expression and metabolomics now allows to explore this in further detail. One example of that is Wærp (2019), who discovered the dietary energy level to affect adipose gene expression greatly, which regulates several aspects of energy metabolism. This could possibly be an explanation of why prepubertal growth can have an effect on days open through gene expression.

The studies of Salte et al. (2020) and Storli et al. (2017) indicate that a higher daily gain in early life leads to heifers reaching puberty at a lower age. If the age of first calving stays the same, then the heifers will go through more estrous cycles, giving the mammary glands enough time to develop before insemination, and can thus lead to a higher milk yield. The heifers in our data were inseminated primarily by age (from 13 to 15 months) and not by weight, meaning that heifers reaching puberty earlier would have more estrous cycles before insemination than heifers reaching puberty at a later stage. This could be the reason that milk yield was most strongly affected by growth rate in between 10 and 15 months of age (Tables 6 and 8).

Krpálková et al. (2014a) found that a moderate daily gain at 850-969 g/day in the prepubertal stage (5-10 months old) gave the highest milk yield in the first lactation for Holstein dairy cows. This is contrary with the findings in the article by Storli et al. (2017), where an optimum for the highest milk yield in the first lactation was a daily gain of 830 g/day in the postpubertal period. Though it is worth to note that the findings in the paper by Storli et al. (2017) was based on NR not Holstein cows, as it has previously been suggested that the relationship between milk and growth is breed-dependant (Hohenboken et al., 1995). While we do not find an optimum, the obtained linear relationship between daily gain across all growth periods was positive in the first lactation, which indicates that an increase in daily gain results in an increase in milk yield in the first lactation. It is however reasonable to assume that there is an optimum (as also discussed above) because obese animals have a higher risk of getting disorders of digestion, infection or reproduction, and might produce less because of it (Daradics et al., 2021). Additionally, as stated previously, Sejrsen et al. (1982) found that increased prepubertal growth may negatively affect milk yield. It has been theorized by Macdonald et al. (2005) that this negative relationship between increased growth and yield, may be masked by the fact that the animals with higher growth rate have a higher body weight (BW) at calving, as they found a decline in BW - corrected milk yield after increased feed access in the prepubertal phase.

In concurrence with our findings, Makuza & McDaniel (1996) found that when days open increased, so did the milk yield. This happened regardless of the yield in previous lactations. Funk et al. (1987) found an optimum of 60-69 days open for the highest milk yield in the following lactation, and cows with less than 40 days dry had a considerably lower milk yield in the following lactation. We did not find an optimum in our results, but we did find a positive linear relationship between days open and milk yield.

In addition to their findings on milk yield, Krpálková et al. (2014a) finds a positive linear effect on prepubertal daily gain on protein content in milk. This is in accordance to our results, where we found a significant effect of prepubertal growth on protein content in milk in the first lactation. Additionally, we found a tendency for an effect of prepubertal growth on protein content across all lactations (significant at 10% level). Moreover, protein percentage in first lactation was significantly affected ($P < 0.05$) by days open, with consistently negatively estimated regression coefficients. This implies that as days open becomes longer, the protein percentage becomes reduced, and this harmonises with protein percentage being heavily affected by the energy balance (Egil Prestløkken, personal communication). Regarding growth rates, however, the regression coefficients were positive and this result rather points to the contrary, mentioned above for NEB and IGF-1, both the causative effects are important in explaining the results (both IGF-1 and NEB).

SCC was not affected by DO in the first lactation, but consistently curvilinear across lactations, indicating a lower optimality for DO, and thus for NEB. The relationship between variables for NEB and SCC in test-day milk have previously been analysed by van Straten et al. (2009), who found that high loss of body weight in early lactation may predispose cows to inflammation of the udder, resulting in instances of high SCC. There have previously been found that NEB can alter the expression of immune response-related genes, resulting in a less effective immune response postpartum (Wathes et al., 2009). Our results implies there may exist an optimum number of days open to achieve low SCC, meaning that energy balance might play a role in SCC in 305 day lactation milk yield across multiple parities since the energy balance likely is more compromised at later parities.

The effect of daily gain on SCC was largest for prepubertal growth, and we find a significant effect of the second order regression coefficient for daily gain both in first lactation and across lactations, resulting in an optimum for the relationship between daily gain and SCC at around 800 grams gain/day. In later periods, however, a linear increase in SCC was estimated for an increased growth rate. In large, the effect of growth on SCC resembled that for DO, and we, in main, interpret it similarly. For completeness, it should be mentioned, that Wærp et al. (2018) found that energy intake through the diet had a significant effect on the expression of genes in related to energy metabolism in adipose tissue in NR heifers, where a high energy diet led to an upregulation of several involved genes.

As mentioned above, the effect of daily gain in the two growth periods after sexual maturation had a positive linear relationship with SCC. It has previously been found that higher yielding cows may have increased levels of SCC (Mukherjee & Dang, (2011)). Since we do find a positive linear relationship between milk yield and daily gain, there might exist an indirect effect of growth on SCC, through milk, in addition to of a direct effect, and as we did not include yield as an effect in the model, it is not known whether yield has an effect of SCC.

It has previously been found that NR heifers can be reared with a high daily gain from 3 months of age until first conception without negative consequences milk performance, as long as post-insemination growth is moderate (Salte et al., 2020). This is in concurrence with our results for 305 days milk yield both for first lactation and across all lactations. We do however find conflicting results regarding the effect of prepubertal growth on other important production parameters for dairy cows. In our results we find an optimal daily prepubertal growth for both SCC in milk and the fertility trait days open. This indicates that while we do find a positive linear effect of higher growth for milk yield, it is not exclusively favorable to aim for a high prepubertal growth, as it might negatively affect other traits. According to the previously discussed results, it may therefore be reasonable to aim for a more moderate daily gain in the prepubertal period. This is in order to avoid the negative effects a stronger growth may have on days open and SCC. Our results point to increasing the daily gain up until around 800 grams per day in the prepubertal period, where it should be possible to attain a positive effect (although not maximized) on milk yield and protein content, without the negative effect a higher gain has on days open and SCC.

By stronger feeding practices, it may be possible to facilitate heifers reaching sexual maturation earlier, allowing them to be bred earlier while still allowing enough estrus cycles to pass for sufficient development of the mammary gland (Salte et al., 2020). This would consequently lower the AFC without significant negative effects on milk yield. By lowering AFC, heifers would enter their productive life earlier, meaning the non-productive period at the start of their lives shortens. Pirlo et al. (2000) found that it was most economically favorable to lower the AFC from 26 to 23-24 months. Contradictory, Krpálková et al (2014b) found that the most profitable rearing practice was one with a more moderate AFC (24.6 - 26.3 months), combined with a daily gain of 700-799 grams/day for growth between 6-14 months of age. This is in accordance to our result, where we argue that a more moderate approach, especially regarding daily gain may be more beneficial.

4.2 Longevity

In order to even assess longevity, it must be defined. There are a number of ways to do this, eg. number of lactations, time between birth and culling or culling rates within herds (Dallago et al., 2021). It is also worth noting that it may be difficult to directly compare our results on longevity with previous findings, as there is a lack of standardization on how longevity is measured (Dallago et al., 2021). For the models used in this paper, it was chosen to use an approach based on the length of the cows' life, with a starting point at birth and an end at the time of culling. The first life stage (t_0) was defined at the stage of growth measurement. The subsequent time periods related to whether or not the cow got calves. This decision was based on the data we had, where all animals had their last weight measured after 575 days of age (Storli et al., 2017). As the heifers were over 18 months of age, we assumed they were initially bred. With this approach, longevity is modelled with repeated records per animal, allowing to properly adjust for the herd effect. The instrumental part of this model is the effect of the culling stage that aims to adjust for the average probability of culling per stage.

An attempt to estimate the heritability of longevity was made by expanding model 3 into a sire model, which includes the genetic relationship of sires over four generations. However, the genetic variance obtained was low, and a likelihood-ratio test for model 3 with and without the genetic effect of sires was performed. The results of this test supported that the genetic effect was not significant, and thus removed as a random effect from the model.

Longevity is a trait of great complexity, with a large number of influencing factors. This may in turn complicate the implementation of longevity in breeding schemes and management recommendations. When the cause of culling is included, the quality of information regarding the reason of culling will vary greatly between farmers. While some provide highly detailed reasons, others report the cause in different categories of "Other causes". This means that the animals culled for "other reasons", may fall under more narrowly aimed categories by others. To further improve the insight on this topic, it would be beneficial to have more detailed information on the culling reasons, as the phenotyping of this variable would have been more precise.

Our results in model 3 show that daily gain in the prepubertal stage has a significant effect on the longevity of an animal. We find that there is a positive linear relationship between prepubertal daily gain and longevity, meaning that the probability of being culled increases with increased prepubertal growth. When we include culling reason as a variable, we see that this is also a highly significant variable, meaning that increased prepubertal growth leads to higher probability of being culled. As seen in Tables 9 and 10, we do find a slightly more significant effect of prepubertal growth for the second order regression in Model 3b than the linear term in Model 3a, which might indicate an optimum. This also applies for Model 4, as Model 4b with the second order regression does have a slightly more significant effect.

Regarding effects of culling reason, poor milk production, fertility problems and temperament issues are the three groups which lead to the highest likelihood of being culled (probabilities of 0.1136, 0.1577 and 0.1602, respectively). Our previous results indicate that increased daily gain through all three growth periods, leads to increased milk yield in all lactations. Because poor milk production is an important culling reason (18.1% of culling), cows with higher milk yield are more likely to be kept in production for a longer period of time. This is in contradiction to the negative impact increased prepubertal growth rate has on longevity. However, the positive impact of higher milk yield might contribute to creating a tendency of an prepubertal optimal growth rate for longevity. Daily growth rate in the prepubertal stage had a significant effect on days open in both model 1 and 2, with an optimum of about 800 g/day. Because days open can be an indicator of low fertility, as previously mentioned, it is possible that daily gain again has an indirect effect on longevity through days open, and thus contributing to the negative effect of daily gain on longevity. Another trait that have a large effect on longevity is poor temperament. While temperament is not likely affected by growth, it is a trait that perhaps should be taken more into account by NDHRS as it seems to be an underrated trait relative to increase the likelihood of a longer productive life.

Dallago et al. (2021) states that a potential option to improve profits of a dairy cow is to increase the length of the cow's productive life. They argue that this is the second most important trait economically in dairy production, after milk yield. While our previously discussed results regarding the effect of daily growth rate on milk, indicate a positive linearity, we also found an optimum for days open, which indicates a negative effect of too high prepubertal growth. Both yield and days open (indicating fertility) are argued above to affect longevity of dairy cows. Increased daily growth rate leads to an increase in milk yield, which again have a positive effect on longevity, but a daily gain exceeding 800 grams/day in the prepubertal period have a negative effect on days open, indicating poorer fertility. As mentioned, poor fertility was one of the most influential culling reasons on decreasing longevity. It is therefore important to find a balance between these two traits also in this respect, as it a higher daily gain increases the likelihood of culling, and thus shortening the life span.

Our results indicate that a high daily gain in the prepubertal stage has a negative impact on longevity. Thus, in respect to increased longevity, it is recommended to have moderate growth in prepubertal heifers, as high daily gain in the prepubertal stage may increase the possibility of being culled.

5.0 Conclusion

In this field study, we find a positive linear effect of increased daily growth rate on milk yield, both in first and across several lactations. Daily gain in the growth period from 10 - 15 months of age seems to have the largest effect on milk yield. For other production traits, we find a stronger effect of prepubertal growth, with several potential optimums for growth, for days open, SCC and longevity. Thus, we argue that it is beneficial to aim for a moderate daily growth rate of heifers, especially in the prepubertal time period, of a size around 800 grams per day.

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