An investigation of the genetic correlation of 200-, 400-, and 600- day weights between beef-on-dairy and beef calves

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Abstract

The expansion of the New Zealand dairy industry has led to an increase in the number of lower-value surplus calves. A mitigation strategy to increase the value of surplus calves is to have them enter the beef market. The aim of this thesis was to investigate the genetic connection between values generated in the dairy-beef progeny test and those generated by the beef progeny test. This was achieved, in part, by researching the genetic correlation between dairy weaning weight, 200-, 400- and 600-day weights in beef-on-dairy compared to beef calves.

The data required for the research was collected in the National Dairy-Beef progeny test and the National Beef progeny test funded by Beef+Lamb NZ. Least squares mean for weaning weight, 200-day weights, 400-day weights and 600-day weights were obtained using a generalised linear model. A single-trait animal model was used to estimate genetic parameters, variance components and calculate heritabilities. A bivariate animal model was also used to estimate the genetic and phenotypic correlations between variables.

The estimated heritabilities for beef-on-dairy cattle were lower than those generated from beef cattle, in particular, weaning weight (0.17 vs. 0.67) and 200-day weight (0.43 vs. 0.78). This difference may be due to maternal effects, management system differences and the focus of breeding programmes. The heritabilities for 400-day and 600-day were high in both beef and beef-on-dairy cattle, therefore, indicating that these traits are under greater genetic influence.

The genetic correlations for growth traits were strong (ranging between 0.60 and 0.96) while the phenotypic correlations were generally lower than the genetic correlations (0.26 and 0.83) within beef cattle and beef-on-dairy cattle. Given these results, the study recommends using beef progeny tests to predict growth traits for both beef and beef-on-dairy systems. This will simplify the breeding process, reduce costs and will enhance the genetic merit of the calves entering the beef industry.

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dWWT	Dairy weaning weight (weight targeted by dairy rearing system)
100d	100-day weight
200d	200-day weight
400d	400-day weight
600d	600-day weight
MWT	Mature weight
EBV	Estimated Breeding Value
FCR	Feed Conversion Ratio
FI	Feed Intake
RFI	Residual Feed Intake
ADG	Average Daily Gain
CEMA	Carcass Eye Muscle Area
IMF	Intramuscular Fat
CRIB	Subcutaneous Fat Depths at the 12th/13th Rib
P8FAT	Rump P8 Fat Depth
CWT	Carcass Weight
Mus%	Muscle Percentage
ME	Metabolizable Energy

Chapter 1

1 Introduction

Low-value surplus calves are a major issue within the New Zealand dairy industry. For a cow to produce milk, she must first produce a calf. Therefore, with 4.9 million dairy cows, it is expected that 4.9 million calves are born into the New Zealand dairy industry every year (Cook, 2014). Of the 4.9 million, approximately 25% are kept as replacements and therefore, around 3.7 million calves are surplus to requirements. The majority (35%) of these surplus calves are slaughtered at a young age (bobby calves) for minimal value due to their undesirable characteristics, while a minority (15%) are finished in a beef system (Edwards et al. 2021).

One possible mitigation for this issue is to increase the value of the surplus calves by having them enter the beef market. The value of calves entering the beef industry is determined by their potential to produce meat and therefore, beef-on-dairy calves attract lower prices than beef calves, especially those with Jersey ancestry. It can be difficult to convince dairy farmers to introduce beef breeds into their breeding programme and equally to convince beef farmers to purchase these calves, leading to difficulties in estimating sales or genetic value as well. The dairy weaning weight, 200-, 400- and 600-day weight estimated breeding values (EBVs) are a vital piece of information for breeding programmes, as these are the parameters that indicate the animal's potential for growth. The value of a calf is therefore linked (at least partially) to their growth potential; however, growth potential from calves of dairy origin is often assumed to be lower (Edwards et al. 2021).

If there is a genetic correlation at either dairy weaning weight, 200-, 400- and 600-day weights between beef and dairy-beef progeny test calves, the number of progeny tests could be reduced, or the results combined. This would potentially increase the accuracy of EBVs available to dairy farmers when looking to introduce beef breeds to their breeding programme, making it simpler to predict the performance of future progeny and increasing the genetic merit of dairy-origin calves entering the beef industry. By increasing prediction accuracy, the value of the progeny should increase as well, both in monetary value and as a

commodity. This could increase the welfare outcomes for dairy calves, societal views, and potential profits for both dairy and beef industries, by reducing the number of surplus dairy calves going to slaughter at a young age for minimal income and meat production. Therefore, the aim of this thesis was to investigate the genetic relationship between records generated in the Dairy-Beef progeny test and those generated by the Beef progeny test. This may allow farmers producing beef-on-dairy to demonstrate the value from greater growth rates to finishers as the growth data can be verified against both beef and beef-on-dairy animals. This was achieved, in part, by researching the genetic correlation between dairy weaning weight, 200-, 400- and 600- day weights in beef-on-dairy compared to beef calves. The data required for the research was collected in the National Dairy-Beef progeny test and the National Beef progeny test funded by Beef+Lamb NZ.

Chapter 2

2 Literature Review

2.1 New Zealand beef industry

Traditionally, the production of beef in New Zealand was from a beef-breeding cow producing calves. There are approximately 3.9 million beef cattle in New Zealand's beef industry, with around 1 million of them being beef-breeding cows (Beef+LambNZ, 2021a). The most common beef breeds are Angus (34%), Holstein- Friesian (13%) and Hereford (11%) (Beef+LambNZ, 2019). As the dairy industry grew in the past decades, an increasing amount of beef production has directly or indirectly originated from dairy herds (Morris & Kenyon, 2014). Around, 65% of New Zealand's beef production is either from bobby calf and cull dairy cow slaughter, or calves being purchased from dairy herds to be finished as beef animals (Morris, 2008), with approximately 44% of calves reared in the New Zealand beef industry being born on a dairy farm (Martín et al., 2021a).

The New Zealand beef industry is distinct from other beef industries. The majority of beef systems around the world use significant quantities of supplements and concentrates, while 95% of the beef cattle's diet is provided by grazed pasture in New Zealand (Morris, 2013). This poses challenges, as pasture quality and quantity can vary dramatically depending on the location, climate, and management. Therefore, the grazed pasture affects the growth rates of the livestock due to the decrease or increase in nutrients supplied to the animal. Nevertheless, New Zealand is a considerable trader of beef worldwide. During the 2022-23 season, New Zealand exported 88% of beef and veal produced in the country, with an estimated revenue of $5.04 billion (Beef+LambNZ & Meat Industry Association, n.d.).

2.2 New Zealand Dairy Industry

The New Zealand dairy industry has doubled in size over the past 40 years, with approximately 2.1 million cows in the 1975-76 season compared with 4.9 million cows in the 2021-22 season (DairyNZ & LIC, 2022). The predominant dairy breeds in New Zealand are Holstein-Friesian x Jersey crossbreed (KiwiCross) (59.2%), Holstein-Friesian (25.2%) and Jersey (7.6%) (DairyNZ & LIC, 2022).

The New Zealand dairy industry differs from the majority of the world as it is pasture- based, utilising grazing instead of total mixed rations diets (Joubran et al., 2021). This means that it is important to align milk production (feed demand) with pasture growth (feed supply) Maintaining a 365-day calving interval is also crucial for the profitability of New Zealand farms. Their primary source of income is milk solids (milkfat and protein), contributing approximately 93% of gross farm revenue, whereas the income from livestock sales only contributes 6% of total gross farm revenue per farm and calf sales contribute approximately 1% (Coleman, 2020; DairyNZ, 2022).

For a cow to produce milk, she must first produce a calf. Therefore, with 4.9 million dairy cows, it is expected that 4.9 million calves are born into the New Zealand dairy industry every year (Cook, 2014). However, only around 25% of these are kept as replacements, and the rest are surplus to requirements (those from late calvers, natural mating's, low genetic merit or in some systems born to heifers). Therefore, a major issue in the dairy industry is the number of surplus calves being produced and those slaughtered at a young age (bobby calves) for minimal value. Bobby calves are only worth a maximum of $2.25/kg carcass weight, and so there is little incentive for farmers to put time and money into caring for these calves (Stringleman, 2021). This is the welfare dilemma of surplus dairy calves.

2.3 Incorporation of dairy into the beef system

A way of mitigating the welfare dilemma of surplus dairy calves is to produce calves that could enter a beef production system. This strategy has led to an increase in the introduction of beef breeds into breeding schemes. The sales of beef semen to be used on dairy cows increased by 41% between 2021 and 2022 at a New Zealand herd improvement company (CRV, 2023). Dairy farmers tend to use beef semen on cows with a low breeding worth because their calves would also have a low breeding worth as well, making them less beneficial to the dairy herd. Beef bulls are also used at the end of the artificial insemination period, to increase the number of in-calf cows. These calves sired by a beef bull can enter the beef industry and be grown for meat, enhancing their value.

Bobby calves are usually slaughtered around 4-7 days of age (Thomas & Jordaan, 2013), whereas beef cattle typically have a slaughter age between 18-22 months (Beef+LambNZ., 2017). However, beef-on-dairy generally has a slaughter target during their second winter to achieve their desired slaughter weight (Martín et al., 2021b). Therefore, they require time to achieve target weights and avoid payment penalties (Bown et al., 2016). This is necessary because cattle from beef-on-dairy systems are usually significantly lighter than cattle from beef systems at weaning, which then carries through to finishing (Martín et al., 2021b). The value of beef calves is determined by their meat production potential and therefore, beef-on-dairy calves can attract lower prices than beef calves. This difference in price makes it difficult to convince dairy farmers to introduce beef breeds into their breeding schemes, because it is complicated to estimate sale or genetic value of the calves produced, due to the lack of research and extension.

2.4 Importance of liveweight Estimated Breeding Values in the evaluation of performance of beef sired animals

Estimated breeding values (EBVs) are the difference between an individual animal's genetics and the genetic level of the population for a specific trait. They are vital for breeding schemes because, on average, half of the animal's EBV for a specific trait is passed onto their progeny (BREEDPLAN, n.d.). There are numerous EBVs used to estimate growth rates in beef cattle, including birth weight, dairy weaning weight, 200-day weight, 400-day weight, 600-day weight, mature weight, feed efficiency and average growth rate. These can be obtained using progeny test data. The 200-day EBV is a useful trait for beef breeders to use to estimate the weight of the animal at weaning. Whereas the 400-day EBV is an important trait for the beef industry especially if the farm is selling animals as yearlings. It allows the breeders to select for a high 400-day weight EBV, increasing the chances of heavier yearlings when sold, therefore increasing profit. Similarly, 600-day EBV is useful for beef farms producing heavy steers. Unfortunately, 200-, 400- and 600-day EBVs are not used on dairy cattle because they are bred for milk production rather than growth. Therefore, it is hard to compare dairy-origin calves with that of beef-origin calves because it is not clear if there is a genetic correlation between the two systems. According to Martín et al. (2021b), beef cattle EBVs can be used to predict the progeny performance of dairy-origin cattle raised for beef. This information can

then be used to inform the dairy industry about the potential trade-offs of using beef breeds to mitigate the issue of bobby calves. It has not yet been determined whether there is a genetic correlation between growth rate EBVs for beef and beef-on-dairy calves.

2.5 Genetic Parameters

2.5.1 Heritability of beef calf growth rate EBV

Heritability is an estimation of the proportion of genetics (rather than environmental influence) that contributes to the differences in the performance of traits between individual animals (DairyNZ, 2014). The heritabilities for weight traits in beef cattle have been extensively investigated (Table 2.1) to optimise breeding schemes and therefore, improve herd performance. Growth trait heritabilities are important for identifying genetic traits that can be utilised to increase growth traits in future progeny. As a result, there has been genetic gain in the beef industry, resulting in more productive herds.

Table 2.1 Heritability of 200-day, 400-day, 600-day and mature weights in a range of beef breeds from published literature.

Trait	Breed	h^2	Reference
200d	Angus	0.29	Roughsedge et al. (2005)
200d	Purebred Hereford	0.50	Núñez-Dominguez et al. (1993)
200d	Purebred Polled Hereford	0.25	
200d	Purebred Angus	0.45	
200d	Crossbred Hereford	0.48	
200d	Crossbred Polled Hereford	0.41	
200d	Crossbred Angus	0.51	
200d	Range of beef breeds	0.32	Bennett and Gregory (1996)
200d	Angus	0.17	Arthur et al. (2001)
200d (m)	Angus	0.17	
200d	Angus	0.14	Torres-Vázquez et al. (2018)
200d (m)	Angus	0.25	
200d (m)	Range of beef breeds	0.20	Weik et al. (2021)
200d	Range of beef breeds	0.14	
400d	Angus	0.27	Arthur et al. (2001)
400d	Range of beef breeds	0.40	Afolayan (2003)
400d	Range of beef breeds	0.33	Afolayan et al. (2007)
400d	Hereford	0.24	Meyer (2004)
400d	Angus	0.36	Roughsedge et al. (2005)
400d	Angus	0.26	Torres-Vázquez et al. (2018)
400d	Purebred Hereford	0.47	Núñez-Dominguez et al. (1993)
400d	Purebred Polled Hereford	0.36	
400d	Purebred Angus	0.56	
400d	Crossbred Hereford	0.59	
400d	Crossbred Polled Hereford	0.49	
400d	Crossbred Angus	0.42	
600d	Range of beef breeds	0.32	Afolayan (2003)
600d	Range of beef breeds	0.32	Afolayan et al. (2007)
600d	Hereford	0.36	Meyer (2004)
MWT	Angus	0.21	Roughsedge et al. (2005)
600d	Angus	0.48	Torres-Vázquez et al. (2018)
MWT	Range of beef breeds	0.48	Weik et al. (2021)

200d: 200-day weight; 400d: 400-day weight; 600d: 600-day weight; MWT: mature weight; (m): maternal; h^2: heritability

2.5.1.1 200-day weight

There is a large range of reported heritabilities for 200-day weight in beef cattle, linked to different breeds as well as different estimation methods (Table 2.1). In Angus cattle, the 200-day weight heritabilities ranged between 0.14 and 0.45 (Roughsedge et al., 2005; Núñez-Dominguez et al., 1993; Arthur et al., 2001; Torres-Vázquez et al., 2018). Therefore, the range of 200-day heritabilities for Angus cattle is low to moderate. However, Núñez-Dominguez et al. (1993), reported the 200-day heritability for crossbred Angus cattle which was slightly higher than purebred Angus cattle (0.51). Whereas, the 200-day weight heritability in Hereford cattle was slightly higher than Angus cattle, ranging between 0.25 and 0.50, polled Hereford had a lower heritability compared to a horned Hereford (Núñez-Dominguez et al., 1993). The crossbred Hereford had a slightly lower heritability compared to the purebred Hereford, 0.50 and 0.48 respectively (Núñez-Dominguez et al., 1993). Several studies also focused on a range of different beef breeds and these 200-day heritabilities ranged between 0.14 and 0.32 (Bennett & Gregory, 1996; Weik et al., 2021).

2.5.1.2 400-day weight

In Angus cattle, the 400-day weight heritabilities ranged between 0.26 and 0.56, which is higher than the 200-day heritabilities for Angus cattle (Arthur et al., 2001; Roughsedge et al., 2005; Torres-Vázquez et al., 2018; Núñez-Dominguez et al., 1993). Unlike 200-day heritability, crossbred Angus had a lower heritability than purebred Angus, 0.42 and 0.56 respectively (Núñez-Dominguez et al., 1993). Hereford cattle had a similar range to Angus cattle, ranging between 0.24 and 0.59, polled Hereford had a lower heritability compared to a horned hereford, 0.36 and 0.47 respectively (Núñez-Dominguez et al., 1993). The crossbred Hereford's (including polled) had a higher heritability in comparison to purebred Hereford cattle (Núñez-Dominguez et al., 1993). The heritabilities for 400-day weight were also investigated in seven breeds of cattle, which included Jersey, Wagyu, Hereford, Angus, South Devon, Limousin and Belgian Blue, and reported estimated heritabilities between 0.33 and 0.40 (Afolayan, 2003; Afolayan et al., 2007).

2.5.1.3 600-day weight

In Hereford cattle, a 600-day weight heritability of 0.36 was reported by Meyer (2004). Whereas, a higher 600-day heritability was reported in Angus cattle, 0.48 (Torres-Vázquez et al., 2018). However, a lower heritability for mature weight was reported for Angus cattle, 0.21 (Roughsedge et al., 2015). The 600-day weight heritability for a range of beef breeds including: Jersey, Wagyu, Hereford, Angus, South Devon, Limousin and Belgian Blue, was reported to be 0.32 in two separate studies (Afolayan, 2003; Afolayan et al., 2007). The mature weight heritability for a range of New Zealand beef breeds was reported to be 0.48 (Weik et al., 2021).

2.5.2 Correlations of live weights in beef cattle

2.5.2.1 Correlations of live weights at different ages in beef cattle

The correlations of birth, 200-, 400-, 600- day and mature weights was investigated in published literature and presented in Table 2.2. Martín et al. (2020), reported that weights at different ages were highly correlated and related to adult size. Therefore, 200-day weight could be used to estimate yearling and mature weights. Others also found high correlations between 200-day and 400-day weights, ranging between 0.79 and 0.89 (Dalton & Morris, 1978; Meyer, 1995; Koch et al., 1973; Arthur et al., 2001). Meyer (2004), estimated both direct (the correlation between an individual's genotype and its own phenotype) and maternal (the correlation between the mother's genotype the offspring's phenotype) correlations of weight at different ages in Hereford cattle, reporting a direct correlation between 200-days and 400-days to be 0.98 and a maternal correlation of 0.94. Therefore, the correlation between 200-day and 400-day weights is relatively high across studies.

Mature weight is the weight when the animal has reached its full maturity, usually after 4 years of age. A high mature weight EBV indicates that the progeny of the animal will be heavier compared to the average. This is important in the beef industry as it will determine the size of the animal at finishing and therefore, breeders can select heavier animals to potentially increase profit. Meyer (2004) reported the direct correlation between 400-days and 600-days was 0.98 and maternal 0.94. As well as the direct correlation between 200-days

and 600-days was 0.81 and the maternal was estimated to be 0.91. This is similar to the research of Roughsedge et al. (2005), who reported correlations between direct 200-day weight and mature weight in various breeds ranging between 0.70 and 0.98, these are displayed in table 2.2.

Birth weight EBV is an estimate of the genetic potential of a calf's birth weight based on the sire and dam's birth weight along with their progeny's birth weights. It allows breeders to select to increase the chance of producing an optimal-sized calf, which needs to be small enough for the dam to successfully give birth and large enough to be able to grow and not hinder slaughter weight. Thomas (2008) estimated the correlation between birth weight and 200-day weight to be between 0.24 and 0.48 with a weighted mean of 0.31. The correlation between birth weight and 200-day weight is low to moderate and therefore, should be used in conjunction with other EBVs when used in breeding schemes.

Table 2.2 Correlations of birth, 200-day, 400-day, 600-day and mature weights (kg) in a range of beef breeds from published literature

Traits	Breed	Correlations	Reference
200d- BW	Range of breeds	0.24 - 0.48	Thomas (2008)
200d - 400d	Range of breeds	0.80	Dalton and Morris (1978)
200d - 400d	Hereford	0.89	Meyer (2004)
200d - 400d	Hereford	0.79	Koch et al. (1973)
200d - 400d	Angus	0.88	Arthur et al. (2001)
200d - 400d (m)	Angus	0.99	
200d - 400d	Hereford	0.98	Meyer (2004)
200d - 400d (m)	Hereford	0.94	
400d- 600d	Hereford	0.98	Meyer (2004)
400d- 600d (m)	Hereford	0.94	
200d - 600d	Hereford	0.81	Meyer (2004)
200d - 600d (m)	Hereford	0.91	
200d - MWT	Range of breeds	0.70 - 0.98	Roughsedge et al. (2005)
200d - MWT (m)	Range of breeds	-0.83	

BW: birth weight; 200d: 200-day weight; 400d: 400-day weight; 600d: 600-day weight; MWT: mature weight; (m): maternal

2.5.2.2 Correlations of live weights at different ages and feed efficiency in beef cattle

Feed efficiency EBVs are helpful traits that can be used by breeders to increase profits, including residual feed intake (RFI), feed conversion ratio (FCR), feed intake (FI), residual gain (RG) and average daily gain (ADG). Arthur et al. (2001) reported the genetic correlation between FI, FCR and RFI and 200-day weight to 0.28, -0.21 and -0.45 respectively. Whereas, Torres-Vázquez et al. (2018), reported 0.68, 0.05 and 0.25 respectively. However, the majority of the estimations in Arthur et al. (2001) had a large standard error and this should, therefore, be taken into consideration when estimating response to selection.

The estimations for FI, FCR and RFI reported by Arthur et al. (2001), and Torres-Vázquez et al. (2018), had similar correlations for 400-day weight compared to 200-day weight. Arthur et al. (2001), reported the genetic correlation between FI, FCR and RFI and 400-day weight to 0.56, -0.09 and -0.26 respectively. Whereas, Torres-Vázquez et al. (2018), reported 0.42, 0.1 and -0.02 respectively, as displayed in table 2.3.

With the exception of FCR, all correlations studied by Torres-Vázquez et al. (2018), decrease when comparing 200-day and 400-day correlations. However, when comparing 400-day and 600-day correlations the feed efficiency EBVs increase with age with the exception of FCR which decreases.

Table 2.3 Correlations of 200-day, 400-day and 600-day weights (kg) with feed efficiency EBVs (FCR, FI, RFI, ADG and RG) in a range of beef breeds from published literature

Traits	Breed	Correlations	Reference
200d - FCR	Angus	-0.21	Arthur et al. (2001)
200d - FCR (m)	Angus	0.39	
200d - FI	Angus	0.28	
200d - FI (m)	Angus	0.45	
200d - RFI	Angus	-0.45	
200d- RFI (m)	Angus	0.22	
200d - ADG	Range of breeds	0.74	Thomas (2008)
200d - RFI	Angus	0.25	Torres-Vázquez et al. (2018)
200d - ADG	Angus	0.45	
200d - FCR	Angus	0.05	
200d - FI	Angus	0.68	
200d - RG	Angus	-0.06	
400d - FI	Angus	0.56	Arthur et al. (2001)
400d- FI (m)	Angus	0.46	
400d- FCR	Angus	-0.09	
400d - FCR (m)	Angus	0.08	
400d - RFI	Angus	-0.26	
400d - RFI (m)	Angus	0.14	
400d - RFI	Angus	-0.02	Torres-Vázquez et al. (2018)
400d - ADG	Angus	0.27	
400d - FCR	Angus	0.10	
400d - FI	Angus	0.42	
400d - RG	Angus	-0.12	
600d - RFI	Angus	0.15	Torres-Vázquez et al. (2018)
600d - ADG	Angus	0.53	
600d - FCR	Angus	-0.12	
600d - FI	Angus	0.61	
600d - RG	Angus	0.09	

200d: 200-day weight; 400d: 400-day weight; 600d: 600-day weight; (m): maternal; FCR: feed conversion ratio; FI: feed intake; RFI: residual feed intake; ADG: average daily gain; RG: residual gain

2.5.2.3 Correlations of live weights at different ages and carcass traits in beef cattle

Beef-on-dairy calves usually have a lower meat production potential compared to beef cattle as their dam is bred for milk production and has reduced genetic potential for meat production. Therefore, investigating the correlations of slaughter characteristics with other important traits such as weights at different ages will provide dairy farmers with valuable data to introduce and optimise the use of beef breeds in their breeding scheme. Slaughter

characteristics include: carcass eye muscle area (CEMA), carcass intramuscular fat (IMF), subcutaneous fat depths at the 12th/13th rib (CRIB), rump P8 fat depth (P8FAT), muscle percentage (MUS%) and carcass weight (CWT). Torres-Vázquez et al. (2018), estimated the genetic correlation between CEMA, IMF, CRIB, P8FAT and CWT with 200-, 400- and 600-day weights in Angus cattle. The correlations involving CRIB and P8FAT were both negative despite the age group. However, the correlations for P8FAT estimated by Afolayan (2003) were different at different ages, the correlation with 600-day weight had a correlation of 0.31 while the 200- and 400-day weights having correlations of 0.09 and 0.00 respectively. The only two EBVs studied by Torres-Vázquez et al. (2018) with a moderate correlation with 200-, 400-, or 600- day weights were IMF and CWT. Carcass weight had the greatest correlations with weight at age traits, 0.64, 0.56 and 0.75 for 200-, 400- and 600- day weights respectively. Therefore, 200-, 400- and 600- day weights can be used to estimate the carcass weight of cattle, allowing farmers to optimise carcass weight increasing profits. Afolayan (2003) estimated the genetic correlations for MUS% and P8FD with weaning, 400-day and 600-day weights in Jersey and Limousin purebreds and crossbred calves. Both the 200- and 600-day weight correlation with MUS% were negative, -0.05 and -0.08 respectively, more correlations are presented in table 2.4. Surprisingly, the correlation between MUS% and the 400-day weight showed a large contrast, yielding a positive correlation of 0.38. Therefore, further investigations may be needed to better understand these correlations and what their implications are in breeding strategies.

Table 2.4 Correlations of 200-day, 400-day and 600-day weights (kg) with carcass traits in a range of beef breeds.

Traits	Breed	Correlations	Reference
200d - CEMA	Angus	0.07	Torres-Vázquez et al. (2018)
200d - IMF	Angus	0.18	
200d - CRIB	Angus	-0.47	
200d - P8FAT	Angus	-0.06	
200d - CWT	Angus	0.64	
200d- MUS%	Range of breeds	-0.05	Afolayan (2003)
200d- P8FAT	Range of breeds	0.09	
400d - CEMA	Angus	0.05	Torres-Vázquez et al. (2018)
400d - IMF	Angus	0.21	
400d - CRIB	Angus	-0.39	
400d - P8FAT	Angus	-0.23	
400d - CWT	Angus	0.56	
400d - MUS%	Range of breeds	0.38	Afolayan (2003)
400d - P8FAT	Range of breeds	0.00	
600d - CEMA	Angus	0.10	Torres-Vázquez et al. (2018)
600d - IMF	Angus	0.19	
600d - CRIB	Angus	-0.26	
600d - P8FAT	Angus	-0.08	
600d - CWT	Angus	0.75	
600d - MUS%	Range of breeds	-0.08	Afolayan (2003)
600d - P8FAT	Range of breeds	0.31	

200d: 200-day weight; 400d: 400-day weight; 600d: 600-day weight; (m): maternal; CEMA: carcass eye muscle area; IMF: carcass intramuscular fat; CRIB: subcutaneous fat depths at the 12th/13th rib; P8FAT: rump P8 fat depth; CWT: carcass weight; MUS%: muscle percentage

2.6 Estimates of genetic parameters for traits of economic importance in beef-on-dairy crossbred cattle

There is increasing interest in the genetics of the crossbreeding between dairy and beef breeds. However, there is limited literature defining growth rate heritabilities in dairy and beef crosses, though literature on growth rate heritabilities in dairy breeds is more readily available.

2.6.1 Heritability of beef-on-dairy calf growth rate estimated breeding values

The gap in literature for beef-on-dairy is because the crossbreeding is a relatively recent strategy to reduce the number of low value surplus dairy calves. Although there is some literature on heritability of growth traits in dairy cattle, this is also limited because growth traits are not as important in the dairy industry. Therefore, it is important to obtain growth

heritabilities to ensure the growth traits in beef-on-dairy are genetically influenced and can be utilised to increase growth traits in future progeny, these are presented in table 2.5.

Table 2.5 Heritability of 200-day, 400-day and 600-day weights (kg) in beef-on-dairy and dairy breeds from published literature

Trait	Sire Breed	h^2	Reference
200d	Holstein Friesian	0.45	Coffey et al. (2006)
200d	Angus & Hereford	0.45-0.59	Coleman (2020)
200d	Angus & Hereford	0.27	Martín et al. (2018)
200d	Holstien Friesian	0.66	Brotherstone et al. (2007)
200d	Range of breeds	0.39	Stephen (2019)
400d	Angus & Hereford	0.25	Martín et al. (2018)
400d (H)	Range of breeds	0.35	Jury et al. (1980)
400d (S)	Range of breeds	0.24	
400d	Range of breeds	0.46	Hocking (1983)
400d	Holstien Friesian	0.56	Brotherstone et al. (2007)
400d	Range of breeds	0.52	Stephen (2019)
600d (H)	Range of breeds	0.42	Jury et al. (1980)
600d (S)	Range of breeds	0.39	
600d	Range of breeds	0.42	Hocking (1983)
600d	Holstien Friesian	0.56	Brotherstone et al. (2007)
600d	Range of breeds	0.62	Stephen (2019)

200d: 200-day weight; 400d: 400-day weight; 600d: 600-day weight; (H): Heifer; (S): Steer

2.6.1.1 200-day weight

The 200-day weight heritability of beef-on-dairy calves varies in the literature (Table 2.5). This may be due to differences between breeds, rearing practices and estimation methods. For example both Martín et al. (2018) and Coleman (2020), used Hereford and Angus bulls crossed with dairy cows to evaluate their 200- and 400-day live weights, these calves were reared in a dairy-beef rearing system weaning calves between 45-90 days they estimated the heritability of 200-day weight to be 0.27 and 0.45-0.59 respectively. Whereas, a study researching genetic aspects of pre-weaning growth rate in artificial weaning systems obtained heritability estimates around 0.45 (Coffey et al., 2006). Brotherstone et al. (2007), estimated a heritability of 0.66 which is slightly greater than the heritabilities reported in other literature. A heritability of 0.45-0.59 is moderate, indicating that there is moderate genetic influence over 200-day weight in dairy-origin cattle. Therefore, there is a potential benefit of

using the 200-day weight EBV for breeding and selection in dairy breeds to improve 200-day weights (Martín et al., 2018).

2.6.1.2 400-day weight

Jury et al. (1980), explored dairy-beef crossbreds including Friesian, Hereford, Angus, Limousin, South Devon, Blonde d'Aquitaine and Charolais, reporting a 400-day weight heritability in heifers and steers of 0.35 and 0.24 respectively. Hocking (1983) investigated weights in a mixture of dairy and beef breeds and estimated a 400-day weight heritability of 0.46. Brotherstone et al. (2007), estimated the 400-day weight heritability of 0.56 in dairy cattle adjusting for pregnancy. However, Stephen (2019), estimated a yearling weight heritability to be 0.37 in Holstein-Friesian dairy cattle. Therefore, this indicates that there is a large range of 400-day weight heritabilities in dairy cattle, which could be due to environmental differences rather than genetic.

2.6.1.3 600-day weight

Both Jury et al. (1980), and Hocking (1983), estimated a 600-day weight heritability of 0.42 in beef-on-dairy cattle. Jury et al. (1980), reported two different heritabilities for heifers and steers, with the steers having a lower 600-day weight heritability of 0.39. There is limited literature on 600-day weight in beef-on-dairy cattle, however, there is literature covering dairy cattle separately. Brotherstone et al. (2007), estimated a 600-day weight heritability of 0.56 adjusting for pregnancy. Similarly to 400-day weight, the variations in the heritability estimates of 600-day weight between studies may be explained by estimation methods, management practices and environmental differences.

2.6.2 Correlations between live weights at different ages in beef-on-dairy crossbred cattle

Due to the recent increasing interest in the integration of beef into the dairy system, there is limited literature on the correlations of different growth traits (Table 2.6). Both Coffey et al. (2006), and Brotherstone et al. (2007), estimated the correlation between 200-day weight and birth weight, but they were both significantly different (-0.08 and 0.44, respectively). Stephen (2019) estimated a genetic correlation between 9-month weight and 15-month weight to be 0.98 and estimated a phenotypic correlation of 0.83. Coffey et al. (2006), and

Brotherstone et al. (2007), estimated genetic correlations of 0.55 and 0.77 respectively. Therefore, there is a large variation in the correlations of 200- and 400-day weight, whereas the correlation estimated for 400- and 600-day weights are very similar across literature. Both Brotherstone et al. (2007), and Jury et al. (1980), both estimated a genetic correlation of around 0.87 and Stephen (2019), reported a genetic correlation of 0.93, however, the phenotypic correlation was lower at 0.81. The genetic correlations between 200- and 600-day weight also varied greatly in the literature, ranging from 0.37 to 0.93 (Brotherstone et al., 2007; Jury et al., 1980; Stephen, 2019). Jury et al. (1980), compared growth rate correlations in steers and heifers. Steers had a lower 100- and 400-day weight correlation in comparison to heifers with 0.57 and 0.67 respectively. Whereas, for 100- and 600-day weight correlation, both sexes had a correlation of 0.67. Yet the correlation for 400- and 600-day weights heifers had a slightly lower correlation compared to steers, 0.85 and 0.87 respectively.

Table 2.6 Correlations of birth, weaning, 100-day, 200-day, 400-day and 600-day weights (kg) in beef-on-dairy and dairy breeds from published literature.

Traits	Sire Breed	Correlations	Reference
200d - 400d	Angus & Hereford	0.55	Coffey et al. (2006)
200d - BW	Angus & Hereford	-0.08	
200d - dWWT	Angus & Hereford	0.77	
400d - BW	Angus & Hereford	0.03	
400d – dWWT	Angus & Hereford	0.55	
200d - BW	Holstien Friesian	0.44	Brotherstone et al. (2007)
200d - 400d	Holstien Friesian	0.77	
200d- 600d	Holstien Friesian	0.37	
400d - 600d	Holstien Friesian	0.87	
100d - 400d (S)	Range of breeds	0.57	Jury et al. (1980)
100d- 400d (H)	Range of breeds	0.67	
100d - 600d (H)	Range of breeds	0.67	
100d - 600d (S)	Range of breeds	0.67	
400d - 600d (S)	Range of breeds	0.87	
400d - 600d (H)	Range of breeds	0.85	
200d – 400d	Range of breeds	0.98	Stephen (2019)
200d – 400d (P)	Range of breeds	0.83	
400d - 600d	Range of breeds	0.93	
400d - 600d (P)	Range of breeds	0.81	
200d – 600d	Range of breeds	0.93	
200d – 600d (P)	Range of breeds	0.72	

BW: birth weight; dWWT: weaning weight; 100d: 100-day weight; 200d: 200-day weight; 400d: 400-day weight; 600d: 600-day weight; (P): phenotypic; (S): Steer; (H): Heifer

2.7 Comparison between beef and beef-on-dairy rearing systems

Addis et al. (2022), explained that Jersey calves have a slower growth rate and do not achieve heavy carcasses, therefore, are not ideal for beef finishing farms. This raises an issue for many dairy farms because 7.6% of New Zealand herds are Jersey and 59.2% are Kiwi Cross, a cross between Holstein-Friesian and Jersey (DairyNZ & LIC, 2022). Martín et al. (2020), reported when using Kiwi Cross a greater proportion of Holstein-Friesian genetics compared to Jersey genetics would produce calves with a greater growth rate and heavier calves, whilst more Jersey genetics will produce lighter calves with a slower growth rate. Apart from genetic factors, management practices also play a crucial role in the difference in growth rates between dairy-raised beef calves and beef calves. New Zealand beef calves are generally weaned from their mother at approximately five to seven months of age (Morris and Smeaton, 2009), while dairy calves are removed from their mother within 24 hours of birth and weaned from milk when they reach between 70 to 90 kg liveweight, depending on their breed (DairyNZ, n.d.). Therefore, the diet and milk production of beef dams will have a greater impact on the growth of the beef calf, in comparison to the dairy industry.

2.7.1 Beef-on-dairy rearing

The standard for dairy-origin calves in New Zealand is an artificial rearing system. This involves removing the calf from the dam within 24 hours of birth and placing them in group housing with other calves. According to DairyNZ (2023), New Zealand is one of the only countries that houses calves in groups, which benefits the calves through interactions with their peers. Typical calf housing requires enough ventilation to reduce the circulation of respiratory diseases but not so much ventilation that it leaves calves exposed to cold winds, with optimal calf temperatures ranging between 15-25°c. It is recommended for each calf to have between 1.5-2.5m^2 with bedding that allows for optimal drainage, wood chip is common whereas stones are known to reduce the temperature of the calves (DairyNZ, 2023).

Calves are either fed once- or twice-a-day or in some cases *ad libitum*. According to Muir et al. (2002), and Beef+LambNZ (2018), once-a-day feeding systems are becoming more popular and are considered the current best practice. The advantage of a once-a-day feeding system is the reduction of labour costs in comparison to a twice-a-day feeding system, which is

important for dairy farmers, especially through the busy calving period. Different milk options are used on the farm including whole milk from the vat, transition milk from the second to eighth milking after calving and milk replacers (NZAGBIZ, n.d.). Whole milk provides the nutrients for growing calves however it is not always cost-effective depending on the milk price. If the milk price is greater than the cost of milk replacer, it would be more beneficial to purchase milk replacer. Whereas, transition milk is a good alternative of the two, as long as it is stored correctly. Calves are usually fed 20 % of their body weight in milk per day to ensure a good growth rate (NZAGBIZ, n.d.). The most important part of artificial rearing is ensuring young calves are receiving high-quality colostrum milk. Lopez and Heinrichs (2022) highlighted the importance of colostrum through the addition of nutritional value for new-born calves as well as the immunoglobulins that have an important role in developing the calves' naïve immune system. Beef+LambNZ (2018) indicated that 10-40% of dairy calves are colostrum deficient, which had both greater death rates and slower growth rates therefore highlighting the significance of colostrum for new-born calves.

Another important aspect of artificial calf rearing is the introduction of concentrate pellets which help form the rumen. Calves will start consuming solid feeds in the first two weeks of life, as the calf gets older and gains weight the reduction of milk intake will increase the amount of solid feed intake, ensuring their rumen will be able to adjust to the new diet. At approximately 70-90 kg depending on their breed, the calves will be gradually weaned onto pasture to avoid health issues or growth checks (DairyNZ, n.d.).

According to Berry (2021), New Zealand dairy-beef calves that are weaned usually get out-wintered on pasture (wintered on pasture, in comparison to housed cattle) and then finished on pasture the following year. Due to pasture production being reliant on the climate, the growth rates of the calves differ during spring and summer compared to summer and autumn, with growth rates in spring and summer being approximately 1-1.5 kg/d compared to 0.8-1.0 kg/d in summer and autumn. The target is to finish before the second winter, approximately 20-22 months of age.

2.7.2 Beef rearing

Rearing beef calves is simpler because beef cows naturally rear their calves. According to Beef+LambNZ (2017), beef breeding cows and sheep are usually farmed together on hill country farms. This is because beef cattle are used to maintain the pasture for the sheep. However, this can sometimes cause the average daily gain of the calf to be less than 1.0 kg/calf/day which is the liveweight gain target for suckled calves on hill country pasture. This is because the growth rate of a suckling calf is determined by the cow's milk supply which depends on the feed available. Therefore, to achieve high growth rates and weaning weights, cows need to be well-fed before and after calving. Beef+LambNZ (2017), suggests an excess of 12 kg DM/day from the day of calving.

Naturally, calves would wean themselves around ten months; however, calves on beef farms are usually weaned at five-seven months of age at weights between 180kg to 240kg. When the calves are weaned, they are commonly moved to lowland farms to be finished on high-quality pasture (Charteris et al., 2000). While 95% of their total diet is comprised of pasture, supplements might be used in winter or dry summers due to the low production of pasture. These supplements include hay, silage, concentrates and forage crops. However, there is a small proportion of beef cattle that are finished in feedlots; this is rare due to the high price of grain in comparison to pasture (Charteris et al., 2000).

2.7.3 Genotype-by-environment system interaction

Genotype-by-environment is an important phenomenon to take into consideration when comparing the sires from the dairy-beef and beef progeny tests due to the difference in production systems. This phenomenon is when genotypes respond differently in one environment compared to another. Robertson (1959) proposed that to ensure genotype-by-environment did not affect the estimation of heritability for a trait, a larger sample size was required in each environment to compare the genetic merit between the two environments. However, Robertson et al. (1960) researched progeny testing bulls at different management levels and found that there was no significant interaction between genotype and environment, indicating that there was consistent genetic ranking across the different management levels. Therefore, these publications indicate that despite the potential genotype-by-environment interactions between the dairy beef and beef progeny tests, a

reliable heritability comparison can be made between the two progeny tests as long as the sample size is appropriate, minimum 10 animals per sire but 20 animals per sire is preferable.

2.8 Growth and Efficiency

Bown et al. (2016), commented on the common belief that beef from traditional British beef breeds is superior to that of dairy-origin even though it is not supported by scientific literature. Dairy breeds tend to have more metabolically active internal organs to allow for greater lactation and therefore dairy breeds tend to have a greater maintenance requirement by at least 15% (Bown et al., 2016). Due to the greater maintenance cost, winter growth rates are usually lower due to the required energy being more than what is available. However, Bown et al. (2016), also indicated that under similar management, there is no difference between beef and beef-on-dairy for growth potential, saleable meat yield, yield of prime cuts and the quality of meat. However, the current New Zealand beef payment system undervalues dairy animals due to the different fat distribution and different muscle shapes. Although there is limited literature comparing the growth of dairy-origin calves and beef calves with their typical rearing management systems, existing studies on similar topics can be used to inform our assumption in this context.

For example, Burggraaf et al. (2020), allocated calves to two different rearing treatments: [1] 4 L milk/day for 5 weeks, then 2 L/ day for two weeks plus concentrate pellets ad libitum for 7 weeks, as well as grazing at 7 weeks, with pellet-weaning at 12 weeks; and [2] 8 L milk/day for 9 weeks, then 4 L for 2 weeks, weaning at 12 weeks, with ad libitum pasture outdoors after the first week. They reported that calves on treatment one were slower growing compared to treatment two and at 12 weeks there was a 7 kg difference and a 11 kg difference at 7 months. Calves on high growing pasture had a 31 kg advantage at 7 months than those on low pasture. The difference in liveweights was maintained till slaughter; however, there was minimal effect on carcass traits and meat quality. This highlights the importance of the quantity of milk the calf obtains and therefore, we can assume that calves that are left on the dam will have greater growth rates due to the increases in milk supply.

Muir et al. (2000), conducted a similar experiment comparing rearing systems for beef-on-dairy calves. Four different rearing systems were compared: system one, calves were fed

twice-a-day for six weeks, had access to pasture and restricted meal from four weeks to 12 weeks; system two fed calves twice-a-day for 10 days followed by once-a-day for 50 days, again had access to pasture and restricted meal from four weeks; system three only had once-a-day feedings for 5 weeks and ad libitum meal before being given access to pasture at 10 weeks; system four is similar to system three however, calves had restricted meal and access to pasture from 4 weeks. At twelve weeks of age, system one had the lowest average live weight of 98 kg, system two and three had the greatest live weights of 108 kg and 110 kg respectively. At slaughter (26 months) the average live weight differences were still apparent; however, these were not statistically significant. The major difference between system one and systems two and three was the amount of meal that the calves had access to, i.e. the more meal they were given, the heavier their live weight. Therefore, this could indicate that if rearing beef-on-dairy calves, concentrate pellets could be used to close the growth rate difference compared to beef calves.

Alongside growth rate, meat quality characteristics are also essential in ensuring the feasibility of incorporating dairy into the beef system. Martín et al. (2020) reported that there was no significant impact of Angus or Hereford sires on the quality of the beef in their beef-on-dairy calves. This is an important piece of information because it allows farmers to select sires based on other characteristics instead (for example, growth or carcass characteristics), therefore producing progeny that have the potential to be fast-growing with heavy carcasses. Martín et al. (2022) also studied sire effects on carcass traits in beef-on-dairy cattle. They reported that the sire does affect most carcass traits of their progeny, with the most difference occurring in the size of the carcass and fat traits. The heaviest sire produced progeny with a carcass weight 46 kg greater than the lightest sire, which was equivalent to $266 greater value. Rib fat depth and marbling score were the most variable in sires and therefore, could be selected for to improve the carcass value. Bittante et al. (2023), studied how different production systems influenced carcass quality in beef-on-dairy calves. They reported that calves reared on dairy farms grew slower than those on farms specialised to fatten the calves. However, the beef quality of the calves raised on dairy farms was better in terms of cooking losses as well as tenderness. They also noted that beef-on-dairy calves that were reared in an intensive system had greater meat quality compared to those from suckler cows.

2.9 Economic and environmental

2.9.1 Effect on economy

One of the major concerns for farmers, within any system, is profit, making it crucial for the rearing of beef-on-dairy calves to be economical for them to use beef in their breeding scheme. There are various cost differences between dairy-origin-beef calves and beef calves. One of these is the increased nutrition required for dairy cattle due to their increase in metabolic requirements. A comparison of an Angus and a Friesian steer by Bown et al. (2016), reported that there would be a 4.73 GJ of metabolic energy difference on average across their lifetime. Using a typical feed cost of $0.15/kg DM, this would represent an additional cost of $67.50 over the lifetime of the Friesian steer compared to the Angus steer, which is equivalent to approximately 5.5% of the total carcass value of a Friesian Steer.

Muir et al. (2000) compared four different systems with various levels of milk and meal used. The cost of calf milk replacer and meal was $91, $127, $127 and $83 per calf for systems one, two, three and four respectively. However, each system required different levels of labour therefore, that needs to be taken into consideration as well as pasture maintenance. To rear a beef-on-dairy calf to slaughter the cost includes weaning, pasture maintenance and labour cost. According to Muir et al. (2000) it would cost approximately $107 for weaning a beef-on-dairy calf artificially, however, it should be noted that this is out dated data and has not be since updated. Beef+LambNZ (2022a), reports with a feed quality of 10 MJME/kgDM, 3209 kg of dry matter is required to grow a Friesian bull from 300kg to 600kg. If per kg of dry matter is $0.15 from 300kg- 600kg it would cost $481. To get a beef calf from weaning to 300 kg it would take approximately an additional 100 days assuming the beef calf is 200 kg at weaning and is gaining 1 kg/day therefore costing an additional $100 ($1.01 per day/cow (Beef+LambNZ, 2012)). With these proxies it would cost at least $688 to produce a beef-on-dairy calf to slaughter.

Whereas, to rear beef cattle to slaughter the only costs are pasture maintenance and labour. According to figures from Beef+LambNZ (2012), the metabolic energy requirements of beef cattle is approximately 24,475 MJME per year, with an energy content of 10 MJME/kgDM, approximately 2448 kg of DM is required. With pasture typically costing $0.15/kg DM

according to Bown et al. (2016), it would cost an estimated $367 per year/cow and approximately $532 from weaning till slaughter, solely on pasture.

Approximately costing at least $156 less to rear a beef calf compared to beef-on-dairy due to the beef-on-dairy calf needing to be artificially reared as well as being weaned earlier therefore, requiring more grass at an earlier age.

2.9.2 Effect of beef-on-dairy crossbreeding on carbon footprint

An area that is becoming more important to farming in New Zealand is the effect on the environment. Van Selm et al. (2021), investigated the potential to reduce greenhouse gases through the utilization of dairy in beef production. They found that greenhouse emissions in dairy-beef animals was 29% lower than that of beef-origin animals. Therefore, by utilising dairy in beef production, the New Zealand beef industry can reduce greenhouse emissions by nearly 2000 kt CO2e (Van Selm et al., 2021). This would allow for a more carbon efficient industry for both the dairy and the beef industries as the product to which carbon can be attributed would increase while potentially decreasing total carbon emissions.

2.10 Summary of literature review

There is an opportunity to mitigate the issue of low value surplus dairy calves by increasing their value by entering them into the beef market. After reviewing the literature, it is evident that there is limited research on the genetic correlation of weaning weight, 200d, 400d and 600d weights between beef-on-dairy and beef calves. Which would be advantageous to enhance the genetic merit of dairy-origin calves entering the beef industry. The objective of this research is to first evaluate whether there is a genetic correlation between weaning weight, 200d, 400d and 600d weights between beef and beef-on-dairy cattle. If there is no genetic correlation the study should then determine the reason for the lack of correlation. If there is a genetic correlation the study should justify what this means for both industries and how they can use this information to enhance their breeding systems and profits.

Chapter 3

3 Material and methods

3.1 Animals and management

The dairy-beef progeny test (DBPT) has been run on 2 different dairy farms and 3 different beef finishing farms, namely Limestone Downs (cohorts born in 2016 and 2017), and then Renown dairy unit (2018-2024) with animals finished at Orakonui and Te Whārua (2018 onwards). The calves were reared using whole milk and milk replacer until they reached industry and farm target weights of 75 kg, approximately 70-90 days of age depending on the sire breed. Calves were weighed fortnightly, weekly once they approached weaning weights. Upon weaning, the calves were transferred to finishing blocks to grow until slaughter. Calves were grouped balancing for bull representation to avoid bias. These were managed as heifers or steer groups, with up to three, management groups of each split to have balanced weights in each group.

The beef progeny test (BPT) has been run on more properties (Caberfeidh, Kepler, Mendip Hills, Rangitaiki, SB, Tautane and Whangara), with calves born to both heifers and cows and which then follow industry practice for weaning and growing cohorts. Calves were grouped balancing for bull representation to avoid bias. As with the DBPT animals, heifers and steers are managed separately and management groups were balanced for liveweight within a group. Numbers of animals per sex, and year by progeny test are presented in table 3.1.

Both dairy-beef and beef dams were artificially mated with beef sires. The sire breeds used in the dairy-beef progeny were Akauishi Wagyu, Angus, Australian Lowline, Belgian Blue, Charolais, Composite, Fleckvieh, Hereford, Limousin, Murray Grey, Normande, Red Devon, Shorthorn, Simmental, South Devon, Speckle Park and Stabilizer. A total of 193 different sires were used in the dairy-beef progeny test. The sire breeds used in the beef progeny test were Angus, Hereford, Simmental and Stabilizer. A total of 467 different sires were used in the beef progeny test.

All calves are DNA tested to verify parentage and have correct sire attribution, calves in the DBPT were born to crossbred dairy cows with varying levels of Holstein-Friesian and Jersey ancestry.

Table 3.1 Number of animals in the Dairy-Beef progeny test (DBPT) and Beef progeny test (BPT), by sex (heifer, steer or bull), by year of birth (2015 to 2022)

Project	DBPT	BPT	Total
Sex			
Heifer	2164	4961	7125
Steer	2547	4861	7408
Bull	-	151	151
Year Born			
2015	-	1785	1785
2016	617	1765	2382
2017	530	2249	2779
2018	710	1155	1865
2019	686	1074	1760
2020	684	911	1595
2021	786	458	1244
2022	698	576	1274

BPT: beef progeny test; DBPT: dairy-beef progeny test

3.2 Measurements and trait definitions

3.2.1 Growth traits

The growth traits required for this analysis were dairy weaning weight (dWWT), 200-day weight (200-d), 400-day weight (400-d) and 600-day weight (600-d). Dairy weaning weight is the weight at which the calves in the DBPT are weaned by weight and then an equivalent age or weight measurement on the BPT calves, which aligned with marking weight. Dairy weaning weight has been adjusted to 90 days, while 200-d, 400-d and 600-d have been standardized to those exact ages. Unfortunately data on carcass traits was not provided and therefore cannot be included in the analysis.

Growth rates were calculated as the change in weight per day of age between two time points. The DBPT animals have a recorded date of birth, so this was used to calculate age at measurement event, weight at age divided by age gave an approximate growth rate. For the BPT animals, date of birth is not known, however, foetal aging was conducted, and mating dates were known, so an assumed 282-day gestation was applied to calculate an approximate birth date, then the same growth rate calculation was used. These were considered to be different traits for the DBPT and BPT animals.

These traits were chosen to be included in the analysis because they are of relevance in the New Zealand beef industry and therefore can be used to contrast or complement with other

genetic evaluations in both New Zealand and internationally. Each weight was recorded unfasted. Due to the commercial farm style, animals were not all the same age at the time of the measurement.

3.2.2 Contemporary groups

The contemporary groups (CG) for beef-on-dairy calves included in the DBPT were made by the year the calf was born (as location is nested in year) and the sex of the calf. Beef-on-dairy were reared on different farms based on their year and sex, therefore by using sex in the CG, the farm is also included in the CG. The years used in the DBPT project were 2015 to 2022, and the sexes were either heifer or steer.

The CG for the beef calves included in the BPT project were made by year the calf was born, the sex and the farm where the calf was reared. The years used in the BPT project were 2015 to 2022 and the calves were either heifers, steers or bulls. There were seven different farms that the beef cattle were reared on. These seven farms were Caberfeidh (Ca), Kepler (Ke), Mendip Hills (MH), Rangitaiki (Ra), SB, Tautane (Ta) and Whangara (Wh).

Grazing mob data for the BPT was not available, therefore grazing mob was not considered in either progeny test.

3.2.3 Data cleaning

Animals with dWWT below 20kg were excluded from the analysis because it is unlikely that an animal was weaned at such a low weight, reducing the risk of including incorrect measurements. Similarly, 200-day weights below 80kg were excluded from the analysis to further minimise the risk of including incorrect data. Any negative liveweight gain in both data sets was excluded from the analysis, to avoid the risk of including incorrect weight measurements. 1201 animals in the beef-on-dairy data set did not have a recorded gestation length, therefore an average gestation length of 282 was assumed, used to calculate birth date where missing.

3.3 Statistical analysis

Data were analysed using SAS 9.4 (SAS Institute Inc., Carey, North Carolina, USA).

Least squares means for dWWT, 200-day weight, 400-day weight and 600-day weight were obtained using a generalised linear model. Age at measurement was fitted as a covariable, contemporary group (year of birth, sex, farm) as a fixed effect and sire as a random effect. Analysed as different data sets for dairy on beef and beef, as the traits in each progeny test were to be considered as different traits within the genetic models.

To obtain least square means for dWWT, 200-day weight, 400-day weight and 600-day weight by sire breed a generalised linear model was used in the same manner as the previous model, however, sire was not fitted in this model due to confounding group classification where 1 sire is representing 1 sire breed, and sire breed was fitted a fixed effect. All sire breeds were analysed within the DBPT dataset, and Angus, Hereford, Simmental, Stabilizer and Unknown sire breed designation was used for the BPT dataset (Unknown was used if sire breed was not consistent or presented in dataset).

Genetic parameters were estimated using ASReml version 4.2 software package (Butler et al., 2023). A similar statistical design to Jayawardana et al. (2023) was carried out, where a single-trait animal model was used to estimate variance components and calculate heritabilities. A bivariate animal model was also used to estimate the genetic and phenotypic correlations. The single-trait model was represented as follows:

$$y = Xb + Za + e$$

where y is the vector of observations for each trait, b is the vector of fixed effects of year born, sex, Contemporary Group and the age at measurement as a covariate, a is the vector of additive genetic effects, and e is the vector of random residual effects. X and Z are incidence matrices relating to the records of fixed and animal additive genetic effects, respectively.

The expected values (E) of the variables were assumed as E(y) = Xb, E(a) = 0, and E(e) = 0. The residuals were assumed to be independently distributed and var(y) = ZAZ' A σ_a^2+ R, var(a)

= $A\sigma_a^2$, and var(e) = $I\sigma_e^2$= R; where σ_a^2 was the animal additive genetic variance, σ_e^2 was the random residual variance, A was the numerator relationship matrix between all the dams, and I was the identity matrix that corresponds to the number of dams with records. The relationship matrix was obtained through ASReml with up to 3 generations of pedigree information.

Heritability (h^2) for each trait was calculated using the following ratio (Falconer & Mackay, 1996):

$$h^2 = \sigma_a^2/\sigma_p^2$$

where σ_p^2 was the phenotypic variance, similar to:

$$\sigma_p^2 = \sigma_a^2+\sigma_e^2$$

In matrix notation, the bivariate model was represented as follows:

$$\begin{bmatrix} \boldsymbol{y_1} \\ \boldsymbol{y_2} \end{bmatrix} = \begin{bmatrix} \boldsymbol{X_1} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{X_2} \end{bmatrix} \begin{bmatrix} \boldsymbol{b_1} \\ \boldsymbol{b_2} \end{bmatrix} + \begin{bmatrix} \boldsymbol{Z_1} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{Z_1} \end{bmatrix} \begin{bmatrix} \boldsymbol{a_1} \\ \boldsymbol{a_2} \end{bmatrix} + \begin{bmatrix} \boldsymbol{e_1} \\ \boldsymbol{e_2} \end{bmatrix}$$

where y_1 and y_2 are the vectors of phenotypic measures for 2 traits; X_1, X_2, Z_1, and Z_2 were design matrices relating the fixed and animal additive genetic effects related to the y_1 and y_2 phenotypes, respectively; b_1 and b_2 were the vectors of fixed effects, a_1 and a_2 were the vectors of random effects of animal for each trait; and e_1 and e_2 were vectors of residual errors.

The expected values of the variables were assumed $E(y_1) = X_1b_1$; $E(y_2) = X_2b_2$; E(a) = 0 and E(e) = 0. The residuals were assumed to be normally distributed with zero mean and following co(variance) structure:

$$var \begin{bmatrix} a_1 \\ a_2 \\ e_1 \\ e_2 \end{bmatrix} = \begin{bmatrix} \mathrm{A}\sigma_{a1}^2 & \mathrm{A}\sigma_{a12}^2 & 0 & 0 \\ \mathrm{A}\sigma_{a12}^2 & \mathrm{A}\sigma_{a2}^2 & 0 & 0 \\ 0 & 0 & \mathrm{I}\sigma_{e1}^2 & \mathrm{I}\sigma_{e12}^2 \\ 0 & 0 & \mathrm{I}\sigma_{e12}^2 & \mathrm{I}\sigma_{e2}^2 \end{bmatrix}$$

Where σ^2_{a1} was the additive genetic variance of the trait 1; σ^2_{a2} was the additive genetic variance of trait 2; and σ^2_{a12} was the additive genetic covariance between both traits. I was an identity matrix of size 14684; σ^2_{e1} was the residual variance for trait 1; σ^2_{e2} was the residual variance of trait 2; and σ^2_{e12} was the residual covariance between both traits.

Genetic correlations (r_g) were estimated as (Falconer & Mackay, 1996):

$$\boldsymbol{r_g} = \frac{\sigma_{a12}}{\sigma_{a1} \times \sigma_{a2}},$$

where σ_{a1} and σ_{a2} were genetic additive standard deviation for trait 1 and trait 2, respectively.

Phenotypic correlations (r_p) were estimated as (Falconer & Mackay, 1996):

$$\boldsymbol{r_p} = \frac{\sigma_{p12}}{\sigma_{p1} \times \sigma_{p2}},$$

where σ_{p12} was phenotypic covariance between phenotypic trait 1 and trait 2.

Chapter 4

4 Results

4.1 Descriptive statistics

Descriptive statistics for number of animal records for weaning weight, 200-day, 400-day and 600-day weight by sex for both the dairy-beef progeny and beef progeny tests are presented in table 4.1.

Table. 4.1 Number of records, mean values and standard deviation for either the dairy-beef progeny test (DBPT) or beef progeny test (BPT) separated by sex for dWWT, 200-day, 400-day and 600-day weights.

Sex		dWWT	200d	400d	600d
BPT					
Heifer	N	4789	4763	3913	3004
	Mean	96.4	195.8	265.1	419.3
	STD	23.81	35.12	36.29	43.69
Steer	N	4695	4713	4131	3322
	Mean	104.5	209.7	279.9	474.3
	STD	24.82	36.49	42.52	70.69
Bull	N	151	145	3	1
	Mean	82.9	170.3	286.7	510.0
	STD	18.88	32.07	55.18	-
DBPT					
Heifer	N	2292	2225	1960	1928
	Mean	89.0	165.1	272.7	411.1
	STD	10.54	22.75	40.55	43.68
Steer	N	2552	2519	2247	2199
	Mean	87.6	168.0	269.9	422.5
	STD	11.24	23.21	39.13	42.17

dWWT: dairy weaning weight; 200d: 200-day weight; 400d: 400-day weight; 600d: 600-day weight; N: number; STD: standard deviation; BPT: beef progeny test; DBPT: dairy-beef progeny test

4.2 Least squares means by contemporary group

4.2.1 Dairy Weaning weight

The least squares means for weaning weight in beef-on-dairy cattle (Table A.1) ranged between 84.5 to 95.9 kg, indicating a small variation off 11.4 kg. Contemporary group 2019S produced the lowest mean weights whereas, 2018S produced the heaviest mean weights ($P<0.05$). Cattle born between 2016 and 2018 tended to have a greater weaning weight than those born between 2019 and 2021 ($P<0.10$), with the exception of 2020H. Between 2016

and 2018, the steer contemporary groups had greater weaning weights than the heifer contemporary groups (P<0.05). However, from 2019 to 2021 heifer contemporary groups tended to have greater weaning weights compared to steer contemporary groups (P<0.10).

The least squares means for dairy weaning weight in beef cattle (Table A.2) ranged between 84.3 to 121.0 kg. Contemporary group Ca2015H produced the lowest least squared mean weight and Ke2021B produced the greatest mean weight (P<0.05). The average of the heifer contemporary groups was 98.56 kg compared to the bull contemporary groups with an average weight of 100.8 kg and the steer's average weight of 105.7 kg. The average of the least squared means for the farms that reared the cattle ranged from 99.5 and 105.8 kg. The average of contemporary groups of each year ranged from 99.3 and 106.2 kg, with 2017 producing heavier calves and 2019 producing lighter calves (P<0.05).

Both beef-on-dairy and beef cattle had a similar minimum mean; however, the beef cattle had a maximum mean of 121.0 kg, which is 25.0 kg more than the maximum of beef-on-dairy cattle at dairy weaning age (P<0.05).

4.2.2 200-day weight

The least squares means for 200-day weight in beef-on-dairy cattle (Table A.1) ranged between 137.2 to 192.3 kg, indicating a relatively small variation of 56.1 kg. Contemporary group 2019S produced the lowest mean weight and 2018S produced the greatest mean weight (P<0.05). In 2018 both the mean weights for heifers and steers contemporary groups were considerably high (179.9 and 192.3 kg respectively). Whereas, in 2019 both the mean weights for heifers and steers contemporary groups were low (156.4 and 137.2 kg respectively). However, the least squared means increased back to be between 168.6 and 183.0 kg from 2020-2022. The mean weights of contemporary groups including heifers were generally lower than steers with the exception of 2017 and 2019 (P<0.10).

The least squared means for 200-day weight in beef cattle (Table A.2) ranged between 164.9 to 264.8 kg. Contemporary group MH2016H produced the lowest least squared mean and Ke2021B produced the greatest mean weight (P<0.05). The average of the heifer contemporary groups was 197.5 kg compared to the bull contemporary groups with an average weight of 199.8kg and the steer's average weight of 211.3 kg. The average of the

least squared means for the farms that reared the cattle ranged from 188.0 and 221.8 kg, on average MH produces lighter calves and SB produces heavier calves (P<0.05). The 2022 season produced the lowest average of least squared means (194.5 kg) whereas, the 2015 season produced the highest average of least squared means (211.9 kg) (P<0.05).

Beef-on-dairy had a minimum least squared mean 27.7 kg lighter than the average least squared mean for the beef cattle. As well as a maximum least squared mean 72.5 kg lighter than the maximum least squared mean for beef cattle, therefore, beef cattle tend to have a heavier 200-day weight in comparison to beef-on-dairy cattle. Least squared means for heifers were generally lower than that of steers, for both beef-on-dairy and beef cattle systems.

4.2.3 400-day weight

The least squared means for 400-day weight in beef-on-dairy cattle (Table A.1) ranged between 222.2 to 328.2 kg. Contemporary group 2020S produced the lowest mean weight and 2016H produced the greatest mean weight (P<0.05). In 2020 both contemporary groups had low least squared means compared to previous years. The average of the heifer contemporary groups was 275.5 kg compared to the steer contemporary groups with an average weight of 267.6 kg, therefore, heifers tend to be heavier than steers at 400 days (P<0.10) which is the opposite of the results for weaning and 200-day weight.

The least squared means for 400-day weight in beef cattle (Table A.2) ranged between 217.8 to 360.9 kg. Contemporary group Wh2019H produced the lowest least squared mean and Ca2015S produced the greatest mean weight (P<0.05). The average of the heifer contemporary groups was 270.8 kg compared to the bull contemporary groups with an average weight of 293.1 kg and the steer's average weight of 287.6 kg. Therefore, on average bulls were heavier at 400- days compared to steers and heifers (P<0.05). The average of the least squared means for the farms that reared the cattle ranged from 250.9 and 319.6 kg, on average Wh produces lighter calves and Ca produces heavier cattle (P<0.05). The 2020 season produced the lowest average of least squared means (250.8 kg) whereas, the 2021 season produced the greatest average of least squared means (312.4 kg) (P<0.05).

Both beef-on-dairy and beef cattle had similar minimum least squared means, 222.2 and 217.8 kg respectively. However, the beef cattle had a maximum least squared mean 32.7 kg greater than beef-on-dairy cattle ($P<0.10$). The beef-on-dairy contemporary groups including heifers had a heavier average mean than steers ($P<0.05$), however, the beef contemporary groups including heifers had lighter average means compared to steers and bulls ($P<0.05$).

4.2.4 600-day weight

The least squared means for 600-day weight in beef-on-dairy cattle (Table A.1) ranged between 347.5 to 448.8 kg. Contemporary group 2020H produced the lowest mean weight and 2016S produced the greatest mean weight ($P<0.05$). The steer contemporary groups had greater mean weights compared with the heifer contemporary groups ($P<0.05$), except for the 2019 cohorts.

The least squared means for 600-day weight in beef cattle (Table A.2) ranged between 380.8 to 549.0 kg. Contemporary group Wh2019H produced the lowest least squared mean and Ca2015S produced the greatest mean weight ($P<0.05$), this is the same as 400-day weight. The average of the heifer contemporary groups was 442.9 kg compared to the bull contemporary groups with an average weight of 524.3 kg and the steer's average weight of 470.3 kg. The average of the least squared means for the farms that reared the cattle ranged from 427.0 and 500.9 kg, on average Wh produces lighter calves and Ke produces heavier cattle ($P<0.05$). The 2018 cohort produced the lowest average of least squared means (444.3 kg) whereas, 2021 produced the greatest average of least squared means (500.9 kg, $P<0.05$).

Beef-on-dairy had a lower minimum least squared mean (347.5 kg) compared to the beef cattle (380.8 kg). The beef cattle had a maximum least squared mean 100.2 kg greater than beef-on-dairy cattle. Therefore, beef cattle at 600 days tend to be heavier than beef-on-dairy cattle at 600 days ($P<0.05$). The beef-on-dairy contemporary groups including heifers had a lighter average mean than steers. This was the same in beef cattle however, bulls had the heaviest weights ($P<0.1$).

4.3 Least squares means by sire breed

Table 4.2 Least squares mean (± standard error of the mean) weight at dWWT, 200-, 400- and 600 days for beef-on-dairy cattle by breed.

Sire breed	n	dWWT	n	200-day	n	400-day	n	600-day
Akauishi Wagyu	28	$78.1^{d} \pm 1.24$	24	$161.2^{cde} \pm 3.29$	0	-	0	-
Angus	1370	$87.4^{ab} \pm 0.33$	1357	$167.1^{c} \pm 0.77$	1261	$271.6^{cb} \pm 0.77$	1231	$415.6^{c} \pm 1.08$
Australian Lowline	24	$84.2^{c} \pm 1.34$	23	$154.0^{e} \pm 3.18$	18	$229.5^{gh} \pm 6.10$	19	$381.0^{gfh} \pm 8.17$
Belgian Blue	58	$84.6^{c} \pm 0.92$	56	$162.6^{cd} \pm 2.15$	55	$238.0^{g} \pm 3.56$	56	$363.2^{ih} \pm 4.98$
Black Hereford	28	$85.8^{bc} \pm 1.26$	28	$159.4^{de} \pm 2.94$	27	$213.3^{i} \pm 4.94$	27	$347.3^{i} \pm 6.88$
Charolais	75	$86.7^{bc} \pm 0.81$	72	$176.3^{ab} \pm 1.92$	51	$302.1^{a} \pm 3.79$	51	$454.3^{a} \pm 5.28$
Composite	21	$90.7^{a} \pm 1.51$	20	$168.9^{cb} \pm 3.56$	20	$222.0^{hi} \pm 5.91$	20	$372.4^{gh} \pm 8.24$
Fleckvieh	64	$87.5^{ab} \pm 0.88$	60	$156.0^{e} \pm 2.14$	61	$249.2^{ef} \pm 3.49$	59	$386.1^{gf} \pm 4.90$
Hereford	1708	$87.5^{ab} \pm 0.32$	1680	$166.7^{c} \pm 0.76$	1477	$272.4^{cb} \pm 0.79$	1452	$416.8^{c} \pm 1.09$
Limousin	114	$89.4^{a} \pm 0.70$	112	$164.4^{cd} \pm 1.73$	114	$255.4^{de} \pm 2.92$	114	$398.5^{ef} \pm 4.03$
Murray Grey	174	$84.8^{c} \pm 0.56$	171	$168.4^{c} \pm 1.31$	141	$272.5^{bc} \pm 2.45$	141	$422.8^{cb} \pm 3.41$
Normande	27	$84.2^{c} \pm 1.30$	28	$141.3^{f} \pm 3.14$	29	$272.5^{bc} \pm 4.83$	29	$426.5^{cb} \pm 6.73$
Red Devon	93	$85.5^{bc} \pm 0.72$	92	$166.8^{c} \pm 1.69$	92	$240.7^{fg} \pm 2.78$	91	$376.1^{gh} \pm 3.93$
Shorthorn	78	$87.1^{abc} \pm 1.15$	75	$165.6^{cd} \pm 2.68$	76	$271.9^{cb} \pm 3.01$	71	$414.7^{cd} \pm 4.33$
Simmental	319	$90.0^{a} \pm 0.40$	309	$177.2^{a} \pm 0.93$	305	$275.4^{b} \pm 1.55$	302	$428.5^{b} \pm 2.16$
South Devon	38	$85.3^{bc} \pm 1.07$	38	$142.5^{f} \pm 2.64$	38	$270.1^{cb} \pm 4.11$	39	$427.0^{cb} \pm 5.67$
Speckle Park	122	$84.3^{c} \pm 0.62$	117	$162.9^{cd} \pm 1.49$	115	$260.2^{d} \pm 2.48$	113	$406.3^{ed} \pm 3.49$
Stabilizer	395	$87.1^{ab} \pm 0.59$	382	$175.9^{ab} \pm 1.39$	322	$269.0^{c} \pm 1.46$	307	$419.3^{c} \pm 2.08$

dWWT: dairy weaning weight; 200d: 200-day weight; 400d: 400-day weight; 600d: 600-day weight; Superscript indicate significant differences P<0.05

Table 4.3 Least squares mean (± standard error of the mean) weight at dWWT, 200-, 400- and 600- days for beef cattle by sire breed.

Sire breed	n	dWWT	n	200-day	n	400-day	n	600-day
Angus	3848	$102.5^{b} \pm 0.68$	4005	$204.4^{b} \pm 1.21$	3536	$282.0^{b} \pm 1.42$	2812	$456.5^{b} \pm 2.15$
Hereford	1178	$102.5^{b} \pm 0.95$	1126	$204.9^{b} \pm 1.73$	1130	$276.7^{b} \pm 1.73$	882	$455.9^{b} \pm 2.81$
Simmental	14	$117.0^{a} \pm 3.98$	15	$256.9^{a} \pm 7.26$	15	$321.3^{a} \pm 7.92$	13	$529.6^{a} \pm 11.19$
Stabilizer	41	$99.1^{b} \pm 2.77$	64	$202.9^{b} \pm 4.38$	57	$274.1^{b} \pm 5.04$	50	$455.2^{b} \pm 6.92$
Unknown	4454	$102.8^{b} \pm 0.44$	4411	$204.4^{b} \pm 0.80$	3309	$276.1^{b} \pm 1.21$	2630	$459.5^{b} \pm 1.50$

n: number; dWWT: dairy weaning weight; 200d: 200-day weight; 400d: 400-day weight; 600d: 600-day weight; Superscript indicate significant differences P<0.05

4.3.1 Dairy weaning weight

The least squares means for dairy weaning weight in beef-on-dairy cattle (Table 4.2) ranged between 78.1 to 90.7 kg, a difference of 12.6 kg. Akauishi Wagyu sires produced the lowest

mean weight and Composite produced the greatest mean weight (P<0.05). Similarly, to the least squares means for beef cattle (Table 4.3) Angus and Hereford had similar weaning weights 87.4 and 87.5 kg respectively. Simmental sires also produced heavy mean weights (90.0 kg), aligning with the results from the beef cattle (Table 4.3).

The least squares means for dairy weaning weight in beef cattle (Table 4.3) ranged between 99.1 to 117.0 kg. The Stabilizer breed produced the lowest mean weight and Simmental's produced the greatest mean weight (P<0.05). However, both Simmental and Stabilizer had high standard errors of 3.98 and 2.77 respectively. Angus and Hereford sires had the same least squares mean of 102.5 kg however, Hereford had a slightly greater standard error.

4.3.2 200-day weight

The least squares means for 200-day in beef-on-dairy cattle (Table 4.2) ranged between 141.3 to 177.2 kg, a difference of 35.9 kg. Normande sires produced the lowest mean weight and Simmental sires produced the greatest mean weight (P<0.05). Angus and Hereford again have similar least squares means, 167.1 and 166.7 kg respectively. Charolais and Stabilizer sires both produced heavy 200-day weights, 176.3 and 175.9 kg respectively. Whereas, Stabilizers in the beef results (Table 4.3) tended to have the lowest least squares means.

The least squares means for 200-day weight in beef cattle (Table 4.3) ranged between 202.9 to 256.9 kg. Similar to weaning weight Stabilizer sires produced the lowest mean weight and Simmental's produced the greatest mean weight (P<0.05). Angus and Hereford sires had similar least squares means, 204.4 and 204.9 respectively.

4.3.3 400-day weight

The least squares means for 400-day in beef-on-dairy cattle (Table 4.2) ranged between 213.3 to 302.1 kg, a difference of 88.8 kg. Black Hereford sires produced the lowest mean weight and Charolais sires produced the greatest mean weight (P<0.05). Angus and Hereford again have similar least squares means, 271.6 and 272.4 kg respectively. Simmental sires have produced high least squares means for beef cattle (Table 4.3) and for weaning weight and 200-day weight in beef-on-dairy, however for 400-day weight the least squares means was 275.4 kg which is only slightly greater than both Angus and Hereford.

The least squares means for 400-day weight in beef cattle (Table 4.3) ranged between 274.1 to 321.3 kg, a difference of 47.2 kg. Similarly to both weaning weight and 200-day weight, Stabilizer sires produced the lowest mean weight and Simmental's produced the greatest mean weight ($P<0.05$). Angus sires produced slightly greater 400-day weights compared to Hereford, 282.0 and 276.7 kg respectively.

4.3.4 600-day weight

The least squares means for 600-day in beef-on-dairy cattle (Table 4.2) ranged between 347.3 to 454.3 kg, a difference of 107.0 kg. Similarly to 400-day weight, Black Hereford sires produced the lowest mean weight and Charolais sires produced the greatest mean weight ($P<0.05$). Angus and Hereford sires have produced similar least squared means for 600-day weight, 415.6 and 416.8 kg. Simmental sires produced the least squares means of 428.5 kg; 11.7 kg greater than Hereford but 25.8 kg below Charolais.

The least squares means for 600-day weight in beef cattle (Table 4.3) ranged between 455.2 to 529.6 kg, a difference of 74.4 kg. Similarly, to weaning, 200 and 400-day weight Stabilizer sires produced the lowest mean weight and Simmental's produced the greatest mean weight ($P<0.05$). However, Angus and Hereford least squares means are similar to Simmental, 456.5 and 455.9 respectively. Therefore, only differ by 1.3 and 0.7 kg respectively.

4.4 Average daily gains for beef-on-dairy and beef cattle at different ages

Tables 4.4, and 4.5 show the mean weight gain, mean average daily gain (ADG), minimum ADG and maximum ADG at different age ranges for both beef-on-dairy and beef cattle individually whereas, Table 4.6 combines both beef and beef-on-dairy cattle. The mean weight gain between 200- and 400-days was 37 kg greater in beef-on-dairy compared with beef cattle. However, beef cattle had greater mean weight gains for weaning weight to 200- and to 600- days, 22.2 and 13.7 kgs respectively. The minimum ADG did not vary significantly between beef and beef-on-dairy cattle, with a maximum difference of 0.10 kg/d. Whereas, there were more significant differences in the maximum ADG. 400-days to 600-days had the

largest difference of 0.98 kg/d followed by weaning weight to 200-days (0.64 kg/d), 200-days to 600-days (0.39 kg/d) and weaning weight to 600-days (0.32 kg/d). Weaning weight to 200-day weight, 200-day to 400-day and 400-day to 600-day had the greatest differences in the mean ADG, 0.20, 0.19 and 0.12 respectively. Whereas the difference in the rest of the age ranges is equal to or less than 0.04. Table 4.6 presents that between weaning and 200-days, the ADG is the highest at 0.86kg/d followed by 400-days to 600-days at 0.81 kg/d. Whereas, the ADG between 200-days and 400-days was the lowest at 0.39 kg/d.

Table 4.4 Mean weight gain, mean average daily gain (ADG), minimum ADG and maximum ADG of beef-on-dairy cattle at different age ranges (Birth -600d).

Trait	N Records	Days	Mean Weight Gain (Kg)	Min. ADG (Kg/d)	Max. ADG (Kg/d)	Mean ADG (Kg/d)
Birth - 600d	3514	600	380.9	0.38	0.90	0.63
Birth - dWWT	4825	90	50.5	0.22	1.33	0.56
dWWT - 200d	4304	110	79.8	0.07	1.52	0.73
dWWT - 400d	4141	310	182.2	0.23	1.06	0.59
dWWT - 600d	3470	510	328.3	0.34	0.95	0.64
200d - 400d	4164	200	101.9	0.01	1.13	0.51
200d- 600d	3487	400	247.0	0.26	0.93	0.62
400d - 600d	3500	200	146.7	0.14	1.22	0.73

dWWT= dairy weaning weight; 200d= 200-day weight; 400d= 400-day weight; 600d= 600-day weight; Min. ADG= Minimum average daily gain; Max. ADG= Maximum average daily gain

Table 4.5 Mean weight gain, mean average daily gain (ADG), minimum ADG and maximum ADG of beef cattle at different age ranges (dWWT -600d).

Trait	N Records	Days	Mean Weight Gain (Kg)	Min. ADG (Kg/d)	Max. ADG (Kg/d)	Mean ADG (Kg/d)
dWWT - 200d	9292	110	102.0	0.04	2.16	0.93
dWWT - 400d	7799	310	169.9	0.13	0.95	0.55
dWWT - 600d	6131	510	342.0	0.33	1.27	0.67
200d - 400d	7963	200	64.9	0.00	1.09	0.32
200d- 600d	6283	400	237.7	0.20	1.32	0.59
400d - 600d	6111	200	170.9	0.07	2.20	0.85

dWWT= dairy weaning weight; 200d= 200-day weight; 400d= 400-day weight; 600d= 600-day weight; Min. ADG= Minimum average daily gain; Max. ADG= Maximum average daily gain

Table 4.6 Mean weight gain, mean average daily gain (ADG), minimum ADG and maximum ADG of beef-on-dairy and beef cattle at different age ranges (Birth -600d).

Trait	N Records	Days	Mean Weight Gain (Kg)	Min. ADG (Kg/d)	Max. ADG (Kg/d)	Mean ADG (Kg/d)
Birth - 600d	3514	600	380.9	0.38	0.90	0.63
Birth - dWWT	4825	90	50.5	0.22	1.33	0.56
dWWT - 200d	13596	110	95.0	0.04	2.16	0.86
dWWT - 400d	11940	310	174.2	0.13	1.06	0.56
dWWT - 600d	9601	510	337.0	0.33	1.27	0.66
200d - 400d	12127	200	77.6	0.00	1.13	0.39
200d- 600d	9770	400	241.0	0.20	1.32	0.60
400d - 600d	9611	200	162.1	0.07	2.20	0.81

dWWT= dairy weaning weight; 200d= 200-day weight; 400d= 400-day weight; 600d= 600-day weight; Min. ADG= Minimum average daily gain; Max. ADG= Maximum average daily gain

4.5 Variance Components and Heritabilities

Results from univariate animal models for the estimation of variance components and heritabilities for growth traits are presented in Table 4.7.

Table 4.7 Variance components (σ_A^2 = additive genetic; σ_e^2= residual; σ_p^2 = phenotypic) and heritability estimates (h^2) with their standard errors (±SE) from univariate analysis for growth traits (dairy weaning weight, 200-, 400- and 600-day weights) in New Zealand beef and beef-on-dairy cattle.

Trait	σ_A^2	σ_e^2	σ_p^2	h^2
Beef-on-dairy (DBPT)				
dWWT	8.01 ± 1.69	38.97 ± 1.69	46.98 ± 1.12	0.17 ± 0.04
200d	111.80 ± 13.23	146.76 ± 10.67	258.56 ± 6.25	0.43 ± 0.05
400d	338.64 ± 41.02	485.17 ± 33.51	823.82 ± 19.79	0.41 ± 0.05
600d	537.27 ± 69.67	711.85 ± 56.45	1249.1 ± 32.99	0.43 ± 0.05
Beef (BPT)				
dWWT	174.95 ± 8.90	86.01 ± 6.34	260.96 ± 4.43	0.67 ± 0.03
200d	639.04 ± 27.73	183.85 ± 18.50	822.90 ± 14.26	0.78 ± 0.02
400d	620.32 ± 36.20	330.73 ± 26.31	951.04 ± 17.56	0.65 ± 0.03
600d	1088.20 ± 66.22	470.33 ± 47.99	1558.60 ± 32.13	0.70 ± 0.03

BPT: beef progeny test; DBPT: dairy beef progeny test; dWWT: dairy weaning weight; 200d: 200-day weight; 400d: 400-day weight; 600d: 600-day weight

The beef-on-dairy heritability estimation for dairy weaning weight was 0.17, which is relatively low, whereas 200-day, 400-day and 600-day heritabilities were moderate (0.43, 0.41 and 0.43 respectively). The beef heritabilities were all moderate to high (0.67, 0.78, 0.65 and 0.70 for dWWT, 200-day, 400-day and 600-day respectively).

Beef cattle also had higher animal, environmental and phenotypic variance for each weight compared to beef-on-dairy, with the exception of 600-day environmental variance. As the number of days increases, the variances also increase for both beef-on-dairy and beef cattle.

4.6 Correlations of growth traits in beef and beef-on-dairy

The genetic correlations between growth traits in beef-on-dairy and beef cattle are presented in Table 4.8. Genetic correlations ranged between 0.60 to 0.96. The lowest correlation was at 400d between datasets (DBPT- 400d and BPT- 400d, r_g= 0.60), although this is still relatively strong. Whereas the highest correlation (0.96) was between DBPT- 600d and DBPT 400-day,

therefore the weight of beef-on-dairy cattle at 400-days is highly correlated with the weight of beef-on-dairy cattle at 600-days.

The phenotypic correlations in Table 4.8 tend to be less than the genetic correlation, ranging between 0.26 to 0.83. The phenotypic correlations tend to be higher when the correlation is between two traits within the same project, in comparison to the correlation involving both beef-on-dairy and beef cattle. The lowest phenotypic correlation was between DBPT-dWWT and BPT-600d, whereas the highest correlation was between BPT-dWWT and BPT-200d.

Table 4.8 Genetic (below the diagonal) and phenotypic correlations (above the diagonal) among growth traits (dairy weaning weight, 200-, 400- and 600- day weights) in New Zealand beef-on-dairy and beef cattle.

	DBPT dWWT	BPT dWWT	DBPT 200d	BPT 200d	DBPT 400d	BPT 400d	DBPT 600d	BPT 600d
DBPT dWWT		0.30 ± 0.07	0.56 ± 0.01	0.29 ± 0.09	0.43 ± 0.01	0.30 ± 0.07	0.44 ± 0.01	0.26 ± 0.08
BPT dWWT	0.87 ± 0.19		0.48 ± 0.08	0.83 ±0.01	0.44 ± 0.09	0.68 ± 0.01	0.51 ± 0.07	0.55 ± 0.01
DBPT 200d	0.80 ± 0.05	0.87 ± 0.13		0.51 ± 0.08	0.67 ± 0.01	0.44 ± 0.08	0.55 ± 0.07	0.39 ± 0.10
BPT 200d	0.77 ± 0.21	0.93 ± 0.01	0.86 ± 0.12		0.48 ± 0.09	0.80 ±0.01	0.75 ± 0.05	0.65 ± 0.01
DBPT 400d	0.69 ± 0.07	0.83 ± 0.15	0.88 ± 0.03	0.84 ± 0.14		0.31 ± 0.12	0.74 ± 0.01	0.35 ± 0.11
BPT 400d	0.88 ± 0.19	0.83 ± 0.02	0.82 ± 0.15	0.89 ± 0.01	0.60 ± 0.22		0.38 ± 0.11	0.76 ± 0.01
DBPT 600d	0.68 ± 0.07	0.93 ± 0.12	0.88± 0.03	0.94 ± 0.11	0.96 ± 0.02	0.72 ± 0.19		0.48 ± 0.08
BPT 600d	0.75 ± 0.22	0.72 ± 0.03	0.71 ± 0.18	0.77 ± 0.02	0.66 ± 0.20	0.85 ± 0.01	0.89 ± 0.14	

BPT: beef progeny test; DBPT: dairy beef progeny test; dWWT: dairy weaning weight; 200d: 200-day weight; 400d: 400-day weight; 600d: 600-day weigh

Chapter 5

5 Discussion

5.1 Inheritance of growth traits

Heritability is important for optimising breeding schemes to distinguish between traits that are under greater genetic influence from those under greater environmental influence. Breeding for a trait with a greater heritability will result in significantly higher genetic gain over subsequent generations.

The heritability for weaning weight (0.17 ± 0.04, Table 4.7) estimate in the reported beef-on-dairy population was low compared to previously reported values (0.45-0.59; Coffey et al., 2006; Coleman, 2020). Whereas the heritability for 200-day weight (0.43 ± 0.05, Table 4.7) in beef-on-dairy was between the estimates of Martín et al. (2018) and Brotherstone et al. (2007), 0.27 and 0.66 respectively. However, it was similar to the 9-month heritability estimation published by Stephen (2019) (0.39). The heritability for 400-day weight in beef-on-dairy cattle was 0.41 ± 0.05 (Table 4.7), which is also similar to range published in literature (0.24-0.56; Table 2.5). Similarly, 600-day weight in beef-on-dairy cattle was 0.43 ± 0.05 (Table 4.7), agreeing with the range of heritabilities in published literature (0.39-0.62; Table 2.5).

The heritability of 200-day weight in beef cattle varies widely in published literature (0.12 to 0.51; Table 2.1). However, the estimated heritability for 200-day weight in this study was greater at 0.78 ± 0.02 (Table 4.7). The 400-day heritability was 0.65 ± 0.03 (Table 4.7) which was also greater than published estimates (0.24-0.36; Table 2.1). Similarly, the 600-day heritability for beef cattle (0.70 ± 0.03) was also greater than previous studies (0.32-0.48; Table 2.1). This variation could be due to maternal effects which were not estimated in this study, and therefore could be part of the additive genetic component.

The dairy weaning weight heritabilities for the two progeny tests differed by 0.50, which is a significant difference. Beef-on-dairy had a lower heritability of 0.17 ± 0.04 whereas, beef cattle had an estimated heritability of 0.67 ± 0.03 (Table 4.7). This may also be due to the management differences between beef-on-dairy and beef calves. Beef cattle dairy weaning weight was measured when the calves were marked and therefore, they were generally

weighed at a set date; whereas beef-on-dairy cattle dairy weaning weight was recorded at the time the calves were weaned, which is generally done at a specific weight. The least squared means in Table A.1 showed less variation in DWWT in beef-on-dairy compared to beef cattle. This suggests the management differences may have influenced the heritability estimates. Another difference in management that could have affected the heritability is the maternal effect. It is assumed that beef cattle are under greater maternal influence for longer through their mother's milk production in comparison to beef-on-dairy that are taken off their mothers within the first 24 hours of life (Back, 2017; Morris, 2017). Twomey et al. (2020), research found that carcass weight and age of slaughter were lower in bucket-reared dairy animals and bucket-reared dairy-beef animals in comparison to suckled-reared animals from a beef × dairy F1 cross dam and suckled-reared animals from a beef × beef cow. This gives the indication that there is a management effect of calves being suckle fed on the dam in comparison to being artificially reared. Therefore, the additive genetic variance for beef cattle will include a portion of maternal effect, giving a potentially inflated estimation of heritability.

Maternal effects may explain the heritabilities for dWWT and 200-day weight also being greater in beef cattle in comparison to beef-on-dairy cattle. Another potential explanation for the differences in the heritabilities for the two projects is that beef cattle are selected for and bred on growth traits whereas, dairy cattle are typically under selection for milk traits (Ahmed et al., 2023). Therefore, there may be reduced variance between the beef cattle than the beef-on-dairy cattle but the variance that is present is an indication of genetic effects. This can be seen in the phenotypic variance in Table 4.7, as beef-on-dairy are not selected for growth traits on both the maternal and paternal sides there is greater total phenotypic variance in the beef animals. Gregory et al. (1995), found that crossbred animals tended to have a greater phenotypic variance compared to purebreds in traits associated with size. They stated that this is due to phenotypic variation being proportional to the mean. Therefore, this may also explain an increased phenotypic variance. Despite the greater variance, because the smaller size of dairy-on-beef calves compared to the beef progeny test cattle, the variance can appear smaller.

Within both progeny tests, there are multiple examples of heterosis effects. There is direct heterosis from a beef sire over a dairy dam. There is also direct heterosis from a beef sire over

a beef dam (both purebred and crossbred). Potentially there is maternal heterosis from either the dairy or beef dams if they are crossbred themselves. The heterosis effects are within the designation of the progeny test, despite this, an individual animal may be more or less crossbred than their contemporary group mean animal. Complete estimation of heterosis effects was not able to be calculated within this study as the genetic make-up of the dam was not always known, meaning that a full dataset of breed proportions would not have been possible for either the dairy-beef progeny test or beef progeny test animals.

5.2 Genetic correlations among growth traits measured in beef-on-dairy and beef cattle

The genetic correlations for growth traits within both beef cattle and beef-on-dairy cattle, as well as between these two groups, were strong ranging from 0.60 to 0.96. The estimated genetic correlation between beef-on-dairy and beef for dWWT was 0.87 ± 0.19 (Table 4.8), therefore, it could be assumed that DBPT animals with a high EBV for dWWT would also produce progeny with high dWWT in the beef industry and vice versa. The genetic correlation between beef-on-dairy and beef for 200-day weight was 0.86 ± 0.12 (Table 4.8), which is considered high and therefore the same conclusion as that for weaning weight could be assumed. However, the genetic correlation between beef-on-dairy and beef for 400-day weight was reduced at 0.60 ± 0.22 which is more moderate, therefore, using a 400-day weight EBV generated in a beef-on-dairy population may not correspond accurately in a beef population. This might be, in-part, due to management differences between the two populations during the winter grazing period. Whereas, the genetic correlation between beef-on-dairy and beef for 600-day weight is high (0.89 ± 0.14) therefore, showing that the different management systems that were affecting the 400-day weight correlation had a reduced impact for the 600-day weight correlation. Therefore, the 600-day weight correlation is a more reliable indicator across beef-on-dairy and beef systems than 400-day weight correlation. This is likely due to the greater time period which allows for the influences of different management systems to diminish and therefore the high genetic correlation. Wanyoike and Holmes (1981), investigated the effects of winter nutrition on the live-weight performance in beef cattle, they report an initial difference in liveweight after wintering. However, there was no significant difference in the final carcass weight or carcass gain per day of age between the two different wintering treatments. Supporting the theory that lower

400-day weight correlations may be due to the difference in wintering systems, but this effect is diminished by 600-days of age.

The correlations between growth traits can be used to inform farmers when the best time is to weigh their calves to estimate certain weights. For example, as presented in Table 4.8, it is slightly more accurate to use beef-on-dairy weaning weight to predict beef-on-dairy 200-day weight in comparison to beef 200-day weight (0.80 ± 0.05 and 0.77 ± 0.21 respectively). Whereas, it is more accurate to predict 400- and 600-day weights in beef cattle (0.88 ± 0.19 and 0.75 ± 0.22 respectively) using beef-on-dairy weaning weights compared with predicting 400- and 600-day weights in beef-on-dairy cattle (0.69 ± 0.07 and 0.68 ± 0.07 respectively). It could be assumed that beef-on-dairy would have a better correlation within its own population, however, this has not been the case in previous research (Kachman et al., 2013). In this dataset the genetic correlation between traits is greater within a progeny test than between for the same trait, with a few minor exceptions.

Weaning weight for beef cattle had a high correlation with 200-day BPT (0.93 ± 0.01) which was higher than with beef-on-dairy 200-day weight (0.87 ± 0.13). Whereas, the correlation between weaning weight in beef cattle and 400-day weights in both beef-on-dairy and beef were the same (0.83) however, beef-on-dairy had a greater standard error (0.15 vs. 0.02). However, 600-day weight in beef-on-dairy had a greater correlation with weaning weight in beef than 600-day weight in beef (0.93 ± 0.12 and 0.72 ± 0.03 respectively). This again may be due to the greater variation in the beef-on-dairy animals.

The genetic correlation between 200-day and 400-day weight in beef-on-dairy was slightly greater than the correlation between 200-day weights in beef-on-dairy and 400-day weights in beef (0.88 ± 0.03 and 0.82 ± 0.15 respectively). The correlation between 200-day and 400-day weight in beef-on-dairy was in the range published in literature (0.55- 0.98; Table 2.6). However, the genetic correlations between 200-day and 600-day weights in beef-on-dairy were significantly greater than the correlation between 200-day weights in beef-on-dairy and 600-day weights in beef cattle (0.88 ± 0.03 and 0.71 ± 0.18 respectively). The beef-on-dairy correlation for 200-day and 600-day weights also aligned with the published literature (0.37-0.93; Table 2.6). Similarly, there was a strong genetic correlation between 400-day and 600-day weight in beef-on-dairy (0.96 ± 0.02) which was slightly greater than the range published

(0.85-0.93; Table 2.6). However, there was a moderate correlation between 400-day weight in beef-on-dairy and 600-day weight in beef cattle (0.66 ± 0.20). This is logical as beef-on-dairy will have similar management systems and environmental conditions throughout their growth period in comparison to beef cattle. Whereas, the correlation between 400-day and 600-day weight in beef cattle was strong (0.85 ± 0.01), however it was less than the correlation published by Meyer (2004), (0.98). 400-day weight in beef with 600-day weight in beef-on-dairy had a correlation of 0.72 ± 0.19, which is still strong but not as strong as the correlation between both beef traits. This may be due to the beef cattle having similar management systems in comparison to beef-on-dairy cattle.

The correlation between 200-day and 400-day weight in beef cattle was slightly higher than with 400-day weight in beef-on-dairy (0.89 ± 0.01 and 0.84 ± 0.14 respectively). The 200-day and 400-day beef correlation was in the range of published literature (0.79-0.98; Table 2.2). Similarly, the correlation between 200-day weights in beef cattle and 600-day weight (0.71 ± 0.18) was also inside the range from published literature (0.70-0.98; Meyer (2004); Roughsedge et al. (2005)). However, the 200-day and 600-day weight correlation was higher in beef-on-dairy than beef cattle, which again may be due to the high variance in the dairy beef progeny test data.

5.3 Phenotypic correlations among growth traits measured in beef-on-dairy and beef cattle

The phenotypic correlation for growth traits both within beef cattle and beef-on-dairy cattle, as well as between these two groups were moderate to strong correlations ranging from 0.26 to 0.83. The phenotypic correlation was generally lower than the genetic correlation and therefore, the environmental impacts are less consistent than the genetic effects. The phenotypic correlation was generally greater between growth traits in the same project. For example, the correlation between 200-day weight and weaning weight in beef cattle was high (0.83 ± 0.01) whereas it was low between 200-day weight in beef cattle and beef-on-dairy weaning weight (0.29 ± 0.09). This is expected because of the different rearing systems between beef and beef-on-dairy cattle. The only exception to this is the correlation between beef-on-dairy 600-day weight and 200-day weight was lower than the correlation between beef-on-dairy 600-day weight and 200-day in beef cattle. This could be explained by the

different management systems for both projects. The beef cattle would have been raised on the dam whereas the beef-on-dairy calves were artificially reared (Twomey et al., 2020). This could potentially cause early restriction on growth which can have a flow-on effect as the calves grow older. It could also be because beef cattle are bred for their growth traits whereas dairy cattle are generally bred for their milk traits (Ahmed et al., 2023).

5.4 Recommended use of progeny tests for predicting growth traits in both beef and beef-on-dairy systems

Based on a strong genetic correlation for most traits, using a beef progeny test is generally a reliable predictor for different growth traits in both beef and beef-on-dairy systems. The correlations using beef progeny test data typically had a strong correlation with beef data, and also strong or in some cases greater correlations with beef-on-dairy data. Whereas, using the beef-on-dairy progeny test data had strong correlations with beef-on-dairy data but sometimes had lower correlations with beef cattle. Therefore, to reduce time and cost, as well as making it simpler for farmers it would be a recommendation to carry out a beef progeny test instead of a beef-on-dairy progeny test to predict growth traits in both beef and beef-on-dairy cattle. Under the requirement that both the birth date and birth weight can be recorded in the beef system accurately.

The dairy industry commonly utilises artificial insemination to mate their cows, 3.9 million out of 4.9 million cows were artificially inseminated in the 2021 -22 season (DairyNZ & LIC, 2022). This gives the ability to increase genetic gain in both the dairy and the beef industry as there will be more progeny coming from fewer animals therefore, increasing the selection intensity.

This should indicate that the genetic merit of calves entering the beef industry will increase. This can be tested by calculating both beef and beef-on-dairy EBVs for weaning weight, 200-day, 400-day and 600-day weights. If the EBV are progressing each year, then this indicates that there is genetic gain in the industry. Martín et al. (2021b), proved that BREEDPLAN EBVs can predict the progeny's performance of beef-on-dairy cattle, indicating that beef-breed data can work in beef-on-dairy systems. However, they did state that it might result in less than the expected 0.5 unit increase per performance unit of EBV. Therefore, the increased EBV from the genetic merit of calves entering the beef industry can be utilised to predict progeny performance of dairy-beef cattle and therefore further increasing genetic gain. This

will be beneficial to New Zealand's dairy industry as a way of mitigating the welfare dilemma of surplus dairy calves. It may help convince dairy farmers to introduce beef breeds into their breeding programme and equally convince beef farmers to purchase these calves.

It would be also beneficial to collect and analyse other traits that would be useful in both beef-on-dairy and beef breeding schemes. These traits could include carcass traits, such as eye muscle area, intramuscular fat and carcass weight, this would allow for predictions of carcass characteristics across the two progeny tests, which would be vital for farmers to optimise their profit by being able to select for these specific carcass traits with increased reliability and therefore, producing a higher producing animal.

Other important traits to analyse are the event differences and ages to measure. Due to the differences between the beef and dairy systems, they have similar events, but they differ. For example, rearing of calves on the beef system is done by keeping calves on the dam until a fixed date (usually 200- days; Morris, 2017) whereas beef-on-dairy cattle are reared artificially and are weaned at a certain weight (70-90kg) (DairyNZ, n.d.). Other major event differences worth analysing are mating and health management.

5.5 Conclusions

This study investigated the genetic connection between values generated in the Dairy-beef progeny test and those generated by the Beef progeny test. The purpose of the study was to determine whether there was a genetic correlation in the growth traits (dairy weaning weight, 200-day, 400-day and 600-day weights) between beef cattle and beef-on-dairy cattle. The analyses determined that the genetic correlations were strong for growth traits within beef cattle and beef-on-dairy cattle, as well as between these two groups, ranging between 0.60 and 0.96. This gives confidence to predict growth traits within and between beef and beef-on-dairy cattle. The phenotypic correlations were generally lower than the genetic correlations, therefore the environmental impacts are lesser than genetic. Given this analysis, the study recommends using beef progeny tests to predict growth traits in both beef and beef-on-dairy systems. This will simplify the breeding process, reduce costs and will enhance the genetic merit of the calves entering the beef industry, therefore, be beneficial to New Zealand's dairy industry as a way of mitigating the welfare dilemma of surplus dairy calves.

Future analysis should estimate the maternal effects to calculate true heritabilities and correlations, as well as taking into account the different management used in beef in comparison to beef-on-dairy systems, which may have affected the estimated heritabilities and correlations. Additionally, future analysis on a wider range of traits such as carcass traits would also be beneficial to inform both the New Zealand dairy and beef industries.

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7 Appendix

Table A.1. Least squares mean (± standard error of the mean) of weights at dairy weaning, 200-, 400- and 600- days for beef-on-dairy cattle included in the Dairy-Beef Progeny test, by contemporary group (year born and sex).

Contemporary group	dWWT	200-day	400-day	600-day
2016H	90.3^{d} ± 0.42	151.5^{h} ± 0.95	328.2^{a} ± 2.01	429.2^{b} ± 2.12
2016S	93.3^{c} ± 0.40	157.6^{g} ± 0.93	302.0^{b} ± 1.59	448.8^{a} ± 2.23
2017H	94.2^{c} ± 0.44	162.2^{f} ± 1.04	272.4^{e} ± 1.83	404.5^{e} ± 2.29
2017S	96.0^{b} ± 0.42	161.9^{f} ± 1.00	289.7^{c} ± 1.77	428.6^{b} ± 2.23
2018H	93.4^{c} ± 0.43	179.9^{c} ± 0.96	283.5^{d} ± 1.94	421.3^{cd} ± 2.25
2018S	97.3^{a} ± 0.37	192.3^{a} ± 0.86	286.0^{cd} ± 1.77	428.4^{b} ± 2.17
2019H	87.0^{e} ± 0.38	156.4^{g} ± 1.23	283.8^{d} ± 1.54	427.7^{b} ± 2.01
2019S	84.6^{f} ± 0.40	137.2^{i} ± 1.21	250.3^{h} ± 1.54	417.5^{d} ± 2.03
2020H	93.6^{c} ± 0.42	174.8^{d} ± 0.98	226.4^{i} ± 1.68	347.5^{g} ± 2.29
2020S	86.3^{e} ± 0.36	178.7^{c} ± 0.86	222.2^{i} ± 1.55	397.1^{f} ± 1.92
2021H	86.7^{e} ± 0.37	174.2^{d} ± 0.95	247.7^{h} ± 1.55	425.2^{bc} ± 2.02
2021S	84.9^{f} ± 0.36	179.6^{c} ± 0.92	257.4^{g} ± 1.45	428.7^{b} ± 1.90
2022H	-	168.6^{e} ± 1.03	286.7^{cd} ± 1.68	-
2022S	-	182.7^{b} ± 1.00	266.0^{f} ± 1.52	-

dWWT: dairy weaning weight; 200d: 200-day weight; 400d: 400-day weight; 600d: 600-day weight: H: Heifer; S: Steer; Superscript indicate significant differences P<0.05

Table A.2. Least squares mean (± standard error of the mean) of weights at dairy weaning, 200-, 400- and- 600 days for beef cattle by contemporary group (farm reared, year born and sex).

Contemporary group	dWWT	200-day	400-day	600-day
Ca2015H	86.7^{b} ± 2.40	201.2^{b} ± 4.37	316.8^{b} ± 4.86	470.9^{bc} ± 7.04
Ca2015S	94.5^{ab} ± 2.18	214.3^{ab} ± 3.96	360.9^{a} ± 4.43	549.0^{a} ± 6.23
Ca2016H	100.8^{ab} ± 2.42	233.9^{a} ± 4.45	273.7^{cd} ± 5.16	-
Ca2016S	108.5^{a} ± 2.57	252.6^{a} ± 4.80	305.4^{bc} ± 5.44	-
Ca2017H	104.4^{ab} ± 2.77	203.9^{b} ± 5.04	327.0^{b} ± 7.43	504.2^{ab} ± 8.02
Ca2017S	107.1^{a} ± 2.82	211.0^{b} ± 5.14	333.9^{b} ± 5.89	538.2^{a} ± 8.36
Ca2018H	104.2^{ab} ± 2.05	191.3^{b} ± 3.74	-	419.6^{c} ± 5.74
Ca2018S	115.0^{a} ± 2.14	207.9^{b} ± 3.90	-	485.2^{bc} ± 7.04
Ke2021B	121.1^{a} ± 14.32	264.8^{a} ± 26.19	346.8^{ab} ± 28.75	-
Ke2021H	94.4^{ab} ± 1.35	191.4^{b} ± 2.40	300.3^{bc} ± 3.81	483.9^{bc} ± 5.40
Ke2021S	98.0^{ab} ± 1.45	195.3^{b} ± 2.59	290.1^{bcd} ± 4.07	517.9^{ab} ± 5.77
Ke2022H	103.2^{ab} ± 1.00	201.1^{b} ± 2.24	285.1^{cd} ± 2.64	-
Ke2022S	107.9^{a} ± 1.07	212.1^{b} ± 2.25	295.8^{bcd} ± 2.60	-
MH2015H	92.2^{b} ± 1.15	188.5^{b} ± 2.14	277.3^{cd} ± 2.35	436.9^{c} ± 3.74
MH2015S	99.6^{ab} ± 1.21	205.5^{b} ± 2.25	304.6^{bc} ± 2.49	454.3^{bc} ± 3.92
MH2016H	95.5^{ab} ± 1.07	164.9^{bc} ± 2.14	277.0^{cd} ± 2.22	468.8^{bc} ± 4.44
MH2016S	98.2^{ab} ± 1.12	169.5^{bc} ± 2.27	290.2^{bcd} ± 2.33	461.4^{bc} ± 3.72
MH2017H	96.9^{ab} ± 1.42	197.3^{b} ± 2.73	262.6^{cd} ± 3.10	-
MH2017S	104.2^{ab} ± 1.50	216.3^{ab} ± 2.78	267.7^{cd} ± 3.21	-
MH2018H	95.6^{ab} ± 1.63	180.8^{b} ± 3.03	251.6^{de} ± 3.3	395.7^{de} ± 6.00
MH2018S	103.7^{ab} ± 1.52	192.1^{b} ± 2.85	292.3^{bcd} ± 3.08	455.1^{bc} ± 5.11
MH2019H	98.0^{ab} ± 1.36	191.4^{b} ± 2.50	245.4^{de} ± 3.12	464.8^{bc} ± 4.69
MH2019S	105.7^{ab} ± 1.30	200.3^{b} ± 2.38	298.7^{bc} ± 2.88	522.2^{ab} ± 3.90
MH2020B	95.5^{ab} ± 3.83	169.4^{bc} ± 7.02	-	524.3^{ab} ± 38.87
MH2020H	100.5^{ab} ± 1.38	177.3^{b} ± 2.58	219.9^{e} ± 2.92	431.9^{c} ± 5.07
MH2020S	107.7^{a} ± 1.48	190.7^{b} ± 2.78	269.4^{cd} ± 3.13	477.4^{bc} ± 4.14
Ra2015H	88.4^{b} ± 0.85	203.7^{b} ± 1.63	271.3^{cd} ± 1.90	453.5^{bc} ± 2.84
Ra2015S	91.9^{b} ± 0.84	212.1^{b} ± 1.60	278.0^{cd} ± 1.76	475.4^{bc} ± 2.75
Ra2016H	103.8^{ab} ± 1.19	201.5^{b} ± 2.12	301.0^{bc} ± 2.80	458.9^{bc} ± 3.72
Ra2016S	110.5^{a} ± 1.18	210.8^{b} ± 2.13	304.5^{bc} ± 2.52	493.5^{ab} ± 3.30
Ra2017H	104.7^{ab} ± 1.21	204.9^{b} ± 2.2	284.9^{cd} ± 2.80	440.4^{c} ± 3.90
Ra2017S	109.3^{a} ± 0.87	211.0^{b} ± 1.62	302.1^{bc} ± 1.94	424.0^{c} ± 2.64
Ra2018H	105.4^{ab} ± 1.39	195.8^{b} ± 2.57	263.6^{cd} ± 2.92	442.6^{c} ± 4.37
Ra2018S	109.9^{a} ± 1.33	205.9^{b} ± 2.46	285.3^{cd} ± 2.83	440.1^{c} ± 5.33
Ra2019H	91.9^{b} ± 1.18	185.3^{b} ± 2.16	269.4^{cd} ± 2.80	476.8^{bc} ± 4.24
Ra2019S	94.4^{ab} ± 1.21	192.1^{b} ± 2.22	271.9^{cd} ± 2.63	485.4^{ab} ± 6.64
Ra2020H	92.3^{b} ± 3.06	193.4^{b} ± 2.27	289.8^{cd} ± 2.82	427.7^{c} ± 4.56
Ra2020S	96.5^{ab} ± 2.25	198.8^{b} ± 2.16	252.1^{de} ± 2.45	409.0^{cd} ± 5.51

SB2015S	105.8^{ab} ± 14.33	221.9^{ab} ± 26.22	253.2^{cde} ± 28.8	485.2^{abc} ± 38.93
Ta2015H	103.7^{ab} ± 1.24	201.2^{b} ± 2.34	282.8^{cd} ± 2.55	458.8^{bc} ± 3.73
Ta2015S	112.4^{a} ± 1.17	214.5^{ab} ± 2.25	328.9^{b} ± 2.40	497.4^{ab} ± 3.56
Ta2016H	91.6^{b} ± 1.16	181.3^{b} ± 2.3	281.2^{cd} ± 2.34	446.5^{c} ± 3.39
Ta2016S	101.3^{ab} ± 1.14	197.9^{b} ± 2.28	329.5^{b} ± 2.35	488.4^{ab} ± 3.18
Ta2017H	102.8^{ab} ± 1.32	187.2^{b} ± 2.31	275.8^{cd} ± 2.50	451.0^{bc} ± 4.12
Ta2017S	107.6^{a} ± 2.76	202.8^{b} ± 3.67	313.3^{b} ± 5.22	-
Ta2018H	99.5^{ab} ± 1.71	187.1^{b} ± 3.17	-	-
Ta2018S	107.6^{a} ± 1.73	204.5^{b} ± 3.19	-	-
Wh2015H	108.8^{a} ± 1.21	228.7^{a} ± 2.31	281.1^{cd} ± 2.66	399.6^{de} ± 3.43
Wh2015S	114.1^{a} ± 1.09	238.9^{a} ± 2.11	282.0^{cd} ± 2.48	440.3^{c} ± 3.17
Wh2016H	98.2^{ab} ± 0.90	207.9^{b} ± 1.67	229.7^{e} ± 2.06	425.3^{c} ± 2.66
Wh2016S	104.4^{ab} ± 0.84	218.7^{ab} ± 1.57	239.1^{e} ± 1.93	475.3^{bc} ± 2.71
Wh2017H	108.3^{a} ± 0.99	224.9^{a} ± 1.82	247.7^{de} ± 2.35	427.0^{c} ± 2.87
Wh2017S	117.0^{a} ± 1.01	237.3^{a} ± 1.85	241.6^{de} ± 2.40	420.5^{c} ± 2.92
Wh2018H	102.4^{ab} ± 1.07	223.0^{a} ± 1.94	271.3^{cd} ± 2.22	443.0^{c} ± 3.09
Wh2018S	111.4^{a} ± 1.01	236.6^{a} ± 1.82	286.8^{cd} ± 2.10	473.2^{bc} ± 6.70
Wh2019H	99.2^{ab} ± 0.94	211.0^{b} ± 1.75	217.8^{e} ± 2.39	380.8^{f} ± 3.79
Wh2019S	106.9^{a} ± 1.01	226.3^{a} ± 1.85	240.2^{de} ± 2.84	391.8^{e} ± 5.64
Wh2020B	100.5^{ab} ± 2.62	193.4^{b} ± 4.99	239.4^{de} ± 28.75	-
Wh2020H	105.0^{ab} ± 1.28	212.0^{b} ± 2.36	237.0^{e} ± 2.90	421.1^{c} ± 4.22
Wh2020S	113.4^{a} ± 1.37	231.5^{a} ± 2.49	248.3^{de} ± 3.02	426.4^{c} ± 5.93
Wh2021B	93.4^{ab} ± 2.44	184.2^{b} ± 4.59	-	-
Wh2021H	91.2^{b} ± 2.41	176.7^{bc} ± 4.42	-	-
Wh2022B	88.6^{b} ± 3.06	187.4^{b} ± 5.6	-	-
Wh2022H	84.3^{b} ± 3.14	177.2^{bc} ± 5.88	-	-

dWWT: dairy weaning weight; 200d: 200-day weight; 400d: 400-day weight; 600d: 600-day weight: H: Heifer; S: Steer; B: Bull; Ca: Caberfeidh; Ke: Kepler; MH: Mendip Hills; Ra: Rangitaiki; SB: SB; Ta: Tautane; Wh: Whangara: Superscript indicate significant differences $P<0.05$