applied sciences

MDPI

Review

Evaluating the Potential of Double-Muscled Angus Sires to Produce Progeny from Dairy Cows to Meet Premium Beef Brand Specifications

Craig Mckimmie [1], Hamed Amirpour Najafabadi [1,*], Hossein Alizadeh [2] and Jon Hickford [2]

[1] Genetics Department, Samen NZ, Hamilton 3300, New Zealand; craig@samen.co.nz
[2] Faculty of Agriculture and Life Sciences, Lincoln University, Lincoln 7647, New Zealand; hossein.alizadeh@lincoln.ac.nz (H.A.); jon.hickford@lincoln.ac.nz (J.H.)
* Correspondence: hamed@samen.co.nz

Simple Summary: This review explores new options for the male offspring of dairy cows and whether they might have the potential to produce high-quality beef that meets the standards of the Certified Angus Beef® brand. This brand is known for its quality and is sold in leading restaurants and fast-food chains. Traditionally, the offspring of dairy cows were not considered capable of producing good quality beef, mainly because of their selection for dairy type and not meat production. However, Angus terminal sires can be developed to mate with dairy cows, and if these terminal sires carry 'double-muscling' genetics, they can produce progeny with the correct muscle size and shape, while also having good marbling, tenderness, and flavour. This potentially meets the requirements to be considered Certified Angus Beef®. This could be a more feed and greenhouse gas (GHG) efficient approach to producing beef, as it would make better use of cattle that might otherwise be disposed for little gain.

Abstract: In response to the increasing global demand for sustainable beef production, this review of the literature was undertaken to explore the possibility of using the progeny of cows in the pasture-based New Zealand dairy production system that are mainly of the Holstein–Friesian, Jersey, and Holstein–Friesian × Jersey-cross breeds, to produce beef that meets the standards demanded by the Certified Angus Beef® (CAB) standard. CAB is a United States of America (USA) benchmark for beef quality. Traditionally, the offspring of dairy breeds have not been suitable for producing high-quality beef due to their genetic makeup and physical characteristics. However, in the USA, breeding programmes have used genetic strategies to boost muscle meat yield in terminal-sire breeds like the Lim-Flex® and NuEra Genetics® T14 cattle lines. In these lines, selection has focused on enhancing muscling and other Angus traits, including ensuring the cattle are homozygous polled and black-coloured. The overall aim has been to alter the phenotypic characteristics of the offspring of dairy cows by terminal-sire crosses, so they resemble the phenotype of purebred Angus cattle and meet the CAB standard. The approach can involve using different alleles of the myostatin gene (*MSTN*) carried by the terminal Angus sires to increase carcass value from the dairy cow-derived male progeny (including the *MSTN* c.821(del11) allele or the myostatin protein p.F94L leucine-containing allele) to increase meat yield and eating characteristics. It is concluded that a targeted selection and mating strategy could provide another source of high-quality beef production, and one that also meets societal demands for better animal welfare and increased sustainability.

Keywords: Certified Angus Beef®; dairy cattle; beef production; genetic strategies; angus phenotype; improved sustainability

Citation: Mckimmie, C.; Amirpour Najafabadi, H.; Alizadeh, H.; Hickford, J. Evaluating the Potential of Double-Muscled Angus Sires to Produce Progeny from Dairy Cows to Meet Premium Beef Brand Specifications. *Appl. Sci.* **2024**, *14*, 6440. https://doi.org/10.3390/app14156440

Academic Editor: Enrico D'Alessandro

Received: 19 June 2024
Revised: 17 July 2024
Accepted: 22 July 2024
Published: 24 July 2024

1. Introduction

In dairy production systems globally, the male progeny of dairy cows are often a cost to the system, while also potentially creating welfare issues. They are typically inferior for meat production as they are derived from genetics selected for dairy production, and many are slaughtered soon after birth because they are deemed to be a cost to production efficiency. In this review, we look at the challenge that wastage of this kind creates in the dairy industry, then suggest an approach that might increase not only the production of good quality beef, but also reduce some inefficiencies in the cattle industries.

2. The Challenge with the Male Progeny of Dairy Cows

Reproductive performance is integral to the overall efficiency of any livestock farming system because animals removed from the system need to be replaced. In dairy production, this need for efficiency is even more pronounced, because cows that have not produced a calf, do not start lactating. This has led to the development of different technologies for improving dairy cow reproductive performance.

The desire to be able to control the gender of livestock progeny has been expressed for many years, and in the dairy industry, this is mainly due to gender-based differences in the value of the progeny. Female dairy calves are typically worth more than male calves, as females can become herd replacements and be milked themselves. Accordingly, 'surplus' dairy calves are nearly all the male calves, plus any female calves not needed as replacements for the milking herd. The fate of the surplus calves varies by country. In Australia and New Zealand, they are often sold as "bobby" calves and slaughtered in the first few days of life, whereas elsewhere they can be sold and reared for longer to produce veal or 'dairy' beef.

Focussing on New Zealand, it is seen by many as a clean and green country that produces dairy and meat products with a low environmental footprint. For example, a systematic review of the literature, removing inconsistencies in life cycle analyses, illustrated that New Zealand had the lowest GWP100 carbon footprint for milk production out of 19 countries [1]. However, the New Zealand dairy industry sends many four-day-old calves to slaughter every year. This occurs in a short space of time given the system is predominantly seasonal and outdoors, with a compressed calving period in the early spring such that lactating cows can have access to high-quality spring pastures. This creates a welfare dilemma, and while the male calves can be humanely managed and slaughtered, potential customers do not like the thought of killing four-day-old animals, regardless of whether valuable products can be obtained from those calves, or not. The calves slaughtered are also not necessarily all male, because while few female calves are killed immediately, they are nevertheless culled from the production system if they are under-performing for key early traits like growth, or if they have other faults.

This challenge is not just peculiar to New Zealand. In Canada and the United States of America, it is also a major issue, and surplus dairy calves commonly experience poor welfare as evidenced by high levels of mortality and morbidity, and negative affective states resulting from limited opportunities to express their natural behaviours [2]. These authors also detail how calves can be transported for more than 24 consecutive hours, and how most calves are sold through auction markets or assembly yards, which increases disease exposure.

There were 4.67 million dairy cows in New Zealand in the 2022–2023 season [3], and approximately the same number of calves were born between July and September, but only one-quarter of these were kept as replacements [4], with the remainder either sold to be raised as beef cattle, killed on the farm, or sold as bobby calves and sent to slaughter. Is New Zealand different to other countries? With hundreds of millions of dairy cattle globally, then one might assume (in the absence of the widespread use of sex-selected semen) that there will also be large numbers of male progeny born globally that may be of limited value to meat production. Countries that do not farm outdoors on pasture, and that are less constrained by seasonal feed availability, may be in a better position to spread out and manage their calf production, but the point remains that calves sourced from dairy genetics have little value, unless female with genetic merit for dairy production.

The Use of Sex-Selected Semen to Reduce Male Dairy Cow Numbers

The use of sex-selected semen technology has emerged as a potential solution to the problem of unwanted male dairy calves. The selection of breeding-only female calves can lead to a more efficient allocation of resources, ultimately streamlining herd management. Studies have demonstrated the economic advantages of sex-selected semen, revealing improvements in milk yield and overall profitability because of the increased number of high-producing dairy cows available to become herd replacements [5,6]. However, alongside these benefits, comes other costs and considerations. One significant issue is the potential impact on fertility. The process of sex selection can damage sperm cells, leading to lower conception rates compared to conventional semen. This reduction in fertility can increase the number of inseminations needed to achieve pregnancy, thereby raising the costs and labour associated with breeding. While sex-selected semen offers the advantage of controlling the sex ratio of dairy cow offspring, it will likely result in more female calves being born that may not have the genetic merit needed to be included in herds as replacements, and that must therefore either be slaughtered, or grown. These unwanted female calves offer no more value than the unwanted male calves for meat production.

3. Producing High-Quality Beef—The Certified Angus Beef® Brand

Sales of the Certified Angus Beef® (CAB) brand began in 1978. Its foundation was the creation of a United States Department of Agriculture (USDA)-certified brand that gave CAB legitimacy [7]. Its attributes are embodied in what is now known as Schedule G-1, Certified Angus Beef® [8]. It is claimed that CAB is the best and largest known beef brand in the world, and that the prime cuts are on the menu of many top restaurants because they represent a pinnacle of quality for having superior taste and texture [9].

Historically, CAB production has (unsurprisingly) relied on beef cattle of the Angus breed. This breed has been described as having distinctive meat marbling and other meat qualities [10]. Angus meat can be described in terms of various quality attributes, and the definition of these attributes can then lay the foundation for creating beef that meets the CAB specification. This could potentially be beef derived from the progeny of dairy cows.

Challenging as it may be, the integration of dairy breed progeny into CAB production offers the potential to enhance the sustainability of beef production, but it does pose both genetic and phenotypic challenges as dairy cows are traditionally bred for traits related to milk production (typically milk volume). Dairy breeds in general do not naturally exhibit the phenotypic traits associated with producing high-quality beef, such as having increased muscle development and mass, and thus higher meat yields. While the primary focus in dairy cattle breeding is not on milk volume alone, the selection for dairy-specific traits can limit the beef production potential of dairy breed progeny.

While there are challenges in achieving the Angus phenotype in the progeny of dairy dams, programmes in the US have adopted genetic approaches that use compensatory traits from terminal sires to achieve that outcome. This includes crossing-in breeds with better muscle characteristics than traditional Angus cattle. Examples include the use of Lim-Flex® (Limousin × Angus-cross cattle) bulls (Australian Limousin Breeders Society; https://www.limousin.com.au/about-the-breed/lim-flex, accessed on 2 February 2024) and the NuEra Genetics® T14 lines (Simmental × Angus-cross genetics; ABS Global, Maddison, Maddison, WI, USA; https://www.absglobal.com/services/nuera-genetics/, accessed on 2 February 2024).

3.1. The Defining Phenotypic Characteristics of Angus Cattle

The Aberdeen Angus breed originated in northeastern Scotland in the early 19th century. Developed primarily in the counties of Aberdeenshire and Angus, the breed was created by selecting for high-quality beef traits in native polled cattle. The breed quickly became known for its superior meat quality, characterised by fine marbling and tenderness. Introduced to the United States in the 1870s, Angus cattle gained popularity and became a foundational breed for beef production. Today, Angus cattle are recognised worldwide for their beef quality and adaptability to various environmental conditions. Angus cattle are naturally polled and characterised by their solid black or red coat colour (http://www.thecattlesite.com/breeds/beef/7/aberdeen-angus/, accessed on 15 February 2024). They are characterised by having high muscularity, increased growth rates, greater body width, and a medium height [11]. The USDA Schedule GLA identifies Angus cattle as predominantly (51% or more) solid black colour [8], but the standard contains other criteria, such as being traceable back to provable Angus parentage, specifically that the qualifying cattle 'must be traceable to one registered parent or two registered grandparents'. Phenotypically they must not display non-Angus characteristics, such as having dairy conformation, Holstein characteristics, or Brahman-type humps and dewlaps.

There are several genes that contribute in a dominant fashion to the Angus phenotype. Firstly, almost all offspring of Angus sires and some Angus-composite sires have the Angus coat colour phenotype. A dominant trait, Angus cattle are homozygous for solid black colour, which leads to all their progeny being black, even if mated to dairy cows. The gene associated with this black coat colour is *MC1R*. It encodes the melanocortin 1 receptor (*MC1R*), which binds the melanocyte-stimulating hormone (α-MSH) that affects eumelanin synthesis. *MC1R* is also known as the Extension (E) locus, and is located on bovine chromosome 18.

Mutation in *MC1R* has been the subject of many studies in various species of mammals, including cattle [12–14], where the occurrence of a functional mutation has been associated with black (or dark) coat colour, while a lack of mutation at the *MC1R* locus has resulted in red, yellow, or white colours. Three alleles have been distinguished at the locus: the dominant black allele (E^D), the recessive red allele (e), and the E^+ allele, which enables the expression of the separate A locus. The order of allele dominance is usually described as $E^D > E^+ > e$. Studies [12] have illustrated that information obtained by sequencing, or other methods, can be used to identify the three alleles of *MC1R*.

Nearly all Angus cattle and most Angus-composite sires are homozygous polled, meaning that all their progeny are polled. This is a defining and highly valued Angus characteristic, but it is far less common in dairy cattle genetics and other beef breeds like the Hereford or Charolais. Angus cattle can also be defined by their classic beef phenotype: having a short head, broad muzzle, and muscular build, albeit characteristics are also true of other beef breeds. It does contrast the typically lean, 'low-muscle' characteristics of dairy cows.

3.2. The Carcass of Angus Cattle

Before a carcass is evaluated for the CAB programme, the phenotypic specification of the live animal must match the USDA Schedule GLA specification for identifying Angus-influenced cattle. In this respect, research has suggested that cattle with Angus genetics tend to produce meat that exhibits better quality and palatability, reinforcing the value of the Angus phenotype in premium beef production [15–17]. To meet the criteria of the CAB brand, carcasses must also have appropriate muscle characteristics and this specification is to ensure that the meat of a CAB carcass has a better muscle-to-bone ratio (meat yield) and a more desirable and uniform appearance.

The specification for better muscling means that cattle having low-muscle dairy-type carcasses are rejected. This criterion is particularly important for the production of high-value cuts, such as the ribeye or longissimus dorsi (LD) muscle. Compared to traditional beef breeds, cattle that have been influenced by dairy farming consistently have a smaller, narrow, and elongated ribeye, a common problem that has been described [18–21]. Due to the narrow muscling and smaller size of the plate, as well as the lack of a traditional beef steak appearance, the meat of Holstein steer carcasses tends to be less sought after by restaurateurs [22].

4. The Use of Myostatin Genetics to Increase Meat Yield in Cattle

Myostatin was identified as a factor causing a 'double-muscling' phenotype in mammals because of the presence of sequence mutations in its gene that can affect expression and lead to the loss of the ability to curtail muscle fibre growth [23]. Since the initial description, there has been considerable interest in this gene for improving meat yield and quality in livestock species.

Numerous studies have been undertaken on the role of myostatin (or *MSTN*) in creating more highly muscled phenotypes in cattle [24–27]). Two of the more commonly investigated alleles of the myostatin gene are discussed in detail below.

4.1. The Myostatin F94L Amino Acid Substitution

The myostatin gene (*MSTN*) nucleotide substitution c.282C>A (rs110065568) results in the substitution of phenylalanine with leucine at position 94 (p.F94L) of the myostatin protein sequence. This substitution had a 'moderately large' effect on muscling in a backcross that used first-cross bulls that were the progeny of Jersey × Limousin or Limousin × Jersey, mated to Jersey and Limousin cows [28]. They described how the c.282A allele, which originated from the Limousin bulls and was not found in the Jersey cattle, was associated with a 5.5% increase in silverside percentage and eye muscle area (EMA), and a 2.3% increase in total meat percentage relative to the c.282C allele. The authors suggested that this would be 'of significant value' for beef cattle producers.

Subsequently, with the same backcross cattle, it was suggested that the c.282A allele did not affect birth and growth traits, but in the Limousin backcross calves, it was associated with an increase in meat weight of 7.3% and 5.9% in Australia and New Zealand, respectively, a reduction in fat depth of 13.9% (below trait mean) for live calves and –18.7% for carcasses, but only in Australia, and not New Zealand [29]. Meat tenderness, pH, and cooking loss for the *Longissimus dorsi* muscle were not affected by F94L. Interestingly, despite the use of Jersey genetics, neither this study nor another study [28] mentioned whether the findings would be of any value to dairy beef systems.

Lines et al. (2009) studied the above lines of Limousin–Jersey cattle too [30], but only those raised in Australia, and reported that c.282A homozygous animals had more tender meat as measured by both peak force and compression. The variant was also responsible for a reduction in the collagen/elastin content of muscle. The c.282A allele had no effect on muscle myofibre diameter in the *Semitendinosus* muscle of the hind leg, even though the variant causes substantial increases in muscle mass. This led them to suggest that the increase in muscle mass of the variant must be due to myofibre hyperplasia and not hypertrophy, and that the myostatin effects on tenderness are caused by changes in the extracellular matrix rather than muscle myofibre diameter. Once again, the potential value of the cattle studied for dairy production was not mentioned.

4.2. The MSTN c.821 Deletion

A second well-researched variant form of the myostatin gene is the *MSTN* c.821(del11) allele (a deletion of 11 nucleotides in the coding DNA sequence from positions 821–831 of *MSTN*). A double-muscled phenotype can be found for many breeds that carry this allele, and it is commonly found as two copies (or in the homozygous form) in Belgium Blue cattle [25]. It can be found in many other breeds including Angus and Angus-cross cattle [31]. In some reports, it has been referred to as the 'myostatin blocker gene'.

Following its discovery, the c.821(del11) allele has been widely studied. For example, it was reported that tenderness and ease of meat fragmentation were significantly higher in myostatin carrier carcasses compared to non-carrier carcasses [32].

In a study undertaken by the Beef CRC (Cooperative Research Centre for Beef Genetic Technologies 200-52012) in Australia, it was reported that as a percentage of cold carcass weight, Angus steers with a single copy of c.821(del11) had an increase in retail yield (67% versus. 63%) with less bone (18% versus 19%) and less fat trim (15% versus. 18%), when compared to non-carrier steers [33]. There was also an increase in eye muscle area

(85 cm^2 vs. 73 cm^2), but there was no difference in marbling scores or rib fat depths. The authors concluded that a breeding programme that utilised a single copy of the 'non-functional' myostatin gene would significantly increase retail beef yield.

A study at the Roslin Institute in Scotland examined the carcass characteristics of Angus-sired cattle that were heterozygous for *MSTN* c.821(del11), comparing them with non-carrier animals [34]. The allele was revealed to significantly increase carcass weights, eye muscle area, and phenotypical muscle expression, but it reportedly had no effect on marbling, or other fat traits.

It was revealed that *MSTN* c.821(del11) allele carriers not only have a higher carcass meat yield, but also have higher yields of expensive cuts of meat. Bulls with the allele have a dressing out percentage average of 70%, when compared to non-carrier genotypes with 64% [35]. This is because of the increased meat content of the carrier carcasses (76% vs. 65% on average) and, hence, total meat is 28% more for the double-muscled animals.

In Senepol cattle, animals heterozygous for *MSTN* c.821(del11) presented a larger area of *Longissimus dorsi* muscle, while their carcasses were leaner with less subcutaneous and intramuscular fat compared to the ones with no copy of the mutation [36]. In Angus cattle, it was revealed that c.821(del11) reduced fatness and increased EMA by 2.8–3.6 cm^2 [37], while another study revealed that net feed intake declined for feedlot finished Angus cattle with one copy of c.821(del11), but that muscling increased, as did the dressing out percentage, retail meat yield, and retail meat-to-bone ratio. The carrier steers had less fat across all carcass fat measurements [38].

In another study, it was revealed that cattle with a single copy of the c.821(del11) allele, when compared to non-carrier cattle, had similar qualities for marbling, shear force (SF), meat colour, and pH, and that the mutation did not appear to reduce meat quality in Angus steers [39]. They also found the inclusion of one copy of the *MSTN* c.821(del11) mutation can increase retail meat yield and maintain qualities valued by consumers, such as improved tenderness, juiciness, flavour, and satisfaction.

This table provides a brief overview of the effects of the *MSTN* c.821(del11) in different cattle breeds emphasizing the impact of this allele on muscle development, carcass characteristics, and meat yield.

4.3. Adverse Effects of MSTN nt821(del11) on Calving Ease

It was reported that *MSTN* c.821(del11) significantly increased muscle score and calving difficulty (rated on a five-point scale from 1 = easy to 5 = caesarean section) and decreased fat depth but did not affect weight at 200 and 400 days in South Devon cattle [40]. The authors argued that the effect on calving difficulty was recessive as the c.821(del11) effect was not additive (i.e., there was no significant effect for heterozygosity), and they noted that there was greater difficulty in calving males than females. The farm also had a significant effect on calving ease.

It was suggested by another study the effect of *MSTN* variation on calving difficulty appeared to be recessive in Piedmontese sire backcrosses to Piedmontese × Hereford and Piedmontese × Angus cows [41]. While not studying the *MSTN* c.821(del11) allele (the cattle had myostatin p.C313Y variation), the authors suggested that the production of heterozygous animals could take advantage of the positive impact of having one copy of the Piedmontese-derived myostatin p.313Y allele on carcass traits, and that it may be a viable option when the value of increased retail product yield is greater than the increased cost associated with calving difficulty. In a follow-up study, they studied crosses of Belgian Blue, Charolais, Hereford, Angus, and composite MARC III cattle [42]. The Belgian Blue cattle were the source of the *MSTN* c.821(del11) allele variation. The study revealed that two copies of c.821(del11) resulted in calves that were more likely to die before weaning. Animals carrying one copy were heavier at birth and at weaning, and their carcasses were leaner and more muscled. The authors discussed how much of the observed loss was likely to be related to the increased birth weight of calves, albeit they also noted that the calves in the study were born in the late winter, when adverse weather in combination with the relatively low amount of extra-muscular fat might contribute to calf loss. They concluded that the use of *MSTN* c.821(del11) is an option to increase retail product yield, but consideration of conditions at calving is important to prevent mortality.

A linearly decreased pelvic area ($p < 0.05$) was reported when the myostatin p.C313Y allele was included in Piedmontese cattle ($p < 0.05$) [43]. The pelvic opening of double-muscled dams was 10 and 6% lower ($p < 0.05$) than in non-double-muscled Charolais [44] or crossbred cows [45], respectively, such that the incidence of dystocia and perinatal mortality was higher in double-muscled cows [45].

In a review of the literature at the time, it was suggested that because of the birthing difficulties encountered by mothers that are homozygous for *MSTN* c.821(del11), having access to a simple typing method for cattle would prove to be a benefit for the breeder, as mothers heterozygous for *MSTN* c.821(del11) have a low frequency of birthing complications, and are also capable of delivering calves homozygous for the *MSTN* c.821(del11) allele [26]. The authors concluded that a decrease in birthing difficulties not only reduces cost, but also reduces the risk of loss of mothers or calves.

A large study was undertaken to investigate associations between 21 known myostatin gene mutations and calving and carcass traits in twelve cattle breeds [27]. The *MSTN* genotypes of 32,770 dam-progeny combinations were used in the association analysis of dystocia, with the genotypes of 129,803 animals used in mixed-model association analyses of carcass weight, conformation, and fat score. The mutant *MSTN* genotypes of c.821(del11), p.Q204X, and p.F94L were all associated ($p < 0.01$) with increased calving problems when present in either the cow or the progeny, but the c.821(del11) allele had the highest association with calving difficulty when the homozygous deletion was present in either the calf or the cow, although the association between the calf's c.821(del11) genotype and calving difficulty differed depending on the c.821(del11) genotype of the dam. The authors suggested that, depending on the dam genotype, a bull with two copies of the c.821(del11) allele can produce progeny with improved carcass merit, while minimizing calving problems.

While Ryan et al. [27] noted that more than 90% of the 32,770 recorded calvings required no assistance at birth, 7.5% required some assistance, 1.3% required considerable assistance, and just 0.3% (109 calving events in total) required veterinary assistance. In an interesting contrast, the incidence of, and risk factors associated with, calving assistance and dystocia in pasture-based dairy herds (there was no mention of *MSTN* variation), from their investigation of 152,641 records of full-term calvings from Holstein–Friesian dams served by artificial insemination (AI) sires of seven breeds, appeared to be higher [46]. The overall average incidence of 'no', 'slight', 'considerable', and 'veterinary' calving assistance was 68.9%, 24.3%, 4.3%, and 2.5%, respectively, with the notable difference being the higher levels of 'considerable' assistance and 'veterinary' assistance for the dairy cattle.

Additionally, an analysis of sires currently used in New Zealand dairy production broadens our understanding (Table 1), but also illustrates how *MSTN* nt821(del11) might be better used. As illustrated in the table, the *MSTN* nt821(del11) Belgian Blues sires have similar calving difficulty and gestation periods compared to the average Friesian sires (born after 1990 with more than 10 recorded calvings). In total, approximately only 38% of the Belgian Blue (*MSTN* nt821(del11)) sires used in New Zealand have acceptable calving ease and gestation periods for the industry (and below all beef sire averaged for both traits). In comparison, the average of the Angus sires is 0.29 for calving difficulty estimated breeding values (eBVs), which is approximately 1% fewer difficult calvings than Friesian sires (1.30) (Table 2). What are called 'dairy suitable' Angus sires have a very similar calving ease and gestation length to the Friesian × Jersey cross dairy sires.

Table 1. Effects of the *MSTN* c.821(del11) in different breeds.

Breed	*MSTN* Mutation	Effect
Belgium Blue	c.821(del11)	Double-muscled phenotype, high tenderness
Angus	c.821(del11)	Increased EMA, reduced fatness
Angus-cross	c.821(del11)	Higher carcass weights, no effect on marbling
Senepol	c.821(del11)	Larger *Longissimus dorsi* muscle, leaner carcasses
Limousin	c.282A	5.5% increase in silverside percentage and EMA, 2.3% increase in total meat percentage

Table 2. Beef sire calving ease and gestation length from New Zealand Animal Evaluation Limited (NZAEL; Hamilton, New Zealand) dairy database *.

Bull Breed	No	Calving Difficulty (eBV) #	Calving Difficulty (Relative)	Calving Difficulty Range	Gestation Length (eBV)	Gestation Length (Relative)
Belgian Blue-*MSTN* nt821(del11)	50	1.09	44	(−1.0 to +7.4)	−0.4	97
Angus	127	0.29	32	(−2.2 to +7.1)	−2.6	94
Current Friesians	6795	1.30	64	(−4.0 to +10.6)	−0.6	97
Suitable Angus	81	−0.29	32	(−2.2 to +0.4)	−3.0	94
Suitable Belgian Blue-*MSTN* nt821(del11)	19	−0.10	47	(−1.0 to +0.4)	−1.2	96
Crossbred	1700	−0.27	67	(−5.0 to +3.9)	−2.4	97
Total	8772	0.42	38	(−4.0 to +7.4)	2.2	95

* Data are available upon request from NZAEL. # Further details about the NZAEL genetic evaluations are available at https://www.dairynz.co.nz/about-us/dairynz-group/nzael/ (accessed on 15 March 2024).

It must also be noted that calving difficulty and carcass merit are reported to be antagonistically correlated in cattle [47], with studies suggesting a moderate-to-strong genetic correlation between calving difficulty and carcass weight in Japanese Black Cattle (0.64 to 0.81) [48] and carcass fleshiness grade in Charolais (0.42) and Hereford cattle (0.54) [49].

In summary, the evidence would suggest that myostatin variation can affect calving ease, but the influence is complex and likely affected by other factors, not just variation in *MSTN*. Appropriate sire selection in conjunction with selection for cows with improved calving ease could be indulged to improve performance.

5. The Establishment of Integrated Beef and Dairy Systems

While the history of cattle domestication is poorly documented, it occurred more than 10,000 years ago [50], there is evidence that milk was in use by the seventh millennium BC [51] in the Near East and southeastern Europe, and while the fate of male progeny from that time is uncertain, it seems likely that they would have been kept for mating and/or meat production in what originally would almost certainly have been a mixed production system. Accordingly, there is nothing new in using the unwanted, typically male progeny of dairy cows for meat production.

In one review, it was explained how the desire to increase profit on dairy farms necessitates consideration of the revenue attainable from the sale of surplus calves for meat production, but noting that the generation of calves with improved growth and carcass merit must not be achieved at the expense of the dairy dam and her ability to calve and re-establish pregnancy early after calving without any compromise to her milk production value [47]. In a separate review, it was also surmised that interest in the generation of more valuable calves for meat production from dairy females is intensifying, and that the most likely vehicle is the use of appropriately selected beef bulls for mating with the dairy females [52].

It was suggested that one of the biggest challenges in achieving the aim of obtaining better meat production from dairy systems is to balance the often antagonistic and heritable traits associated with calving performance and carcass merit [47]. One tool to do this would be to create selection indices that include estimates of breeding value for both calving ease and meat production traits. The authors suggested this might include selection for direct calving difficulty, gestation length; calf mortality, feed intake, carcass merit (including weight, conformation, and fat), docility, and whether the calf was polled. In an analysis of 3835 bulls from 14 breeds used to artificially inseminate dairy cows, the study reported that superior carcass and growth performance can be achieved with the appropriate selection of beef bulls for use on dairy females, and with only a modest increase in the negative effect on cow performance (i.e., 2–3% greater dystocia expected and a 6-day-longer gestation length).

The use of phenotypic breeding values for better beef production from dairy cattle progeny is also not unprecedented. For example, in Sweden, Denmark, and Finland, Nordic Cattle Genetic Evaluation (http://www.nordicebv.info/about-nav, accessed on 2 February 2024; [53]) has developed joint Nordic breeding values that aid farmers in their choice of the right beef sires to use on their dairy cows to enable better opportunity for a profitable production of beef × dairy crossbred animals. In this context, it was described how Sweden benefitted from the integration of dairy and beef production into environmentally and economically sustainable systems, and how this has led to novel breeding and management practices to enable the production of better-quality meat [54]. In New Zealand, it was suggested that farmers consider using BREEDPLAN (https://breedplan.une.edu.au/, accessed on 2 February 2024) eBVs when selecting sires to mate to dairy cows, so as to ensure the resulting calves are born safely and on time, and that they will grow well to produce carcasses of suitable meat and fat composition [55], albeit similar evaluations are also available from the dairy industry's organisation for genetics and animal evaluation, NZAEL, and could be better aligned with valuable dairy traits in appropriate selection indices.

Foraker et al. describe the value of the meat from the progeny of dairy cows produced using beef semen [56]. They illustrated that prime cuts from beef × dairy cattle could be presented alongside those from conventional beef cattle without consumer discrimination based on colour or steak shape, as might be experienced for products derived purely from dairy cattle. Beef from beef × dairy cattle also had similar parameters for eating quality (flavour, tenderness, and juiciness), exhibiting similar, or improved performance for these parameters, relative to beef from conventional beef cattle. Perhaps unsurprisingly, it has been illustrated that using low birthweight beef bulls, such as Angus bulls over Jersey cattle does not adversely affect the dairy production traits of the dam, confirming the viability of the strategy for integrating beef genetics, without compromising dairy performance [57].

Another study also illustrated the impact of dairy breed genetics on carcass characteristics, with this study revealing that Jersey cattle genetics from dairy cows may negatively influence progeny carcass weight and meat quality (the occurrence of yellow fat), underscoring the need for improved strategies to produce more and better beef [58]. Until recently though, the meat derived from the progeny of dairy cows, especially Jersey cattle, has typically been deemed to be less suitable for premium beef markets and was often relegated to producing cheaper products.

The Use of Myostatin Genetics to Improve Meat Traits in Beef-Sired Dairy-Cross Calves

Variations in *MSTN* may have a role to play in producing superior beef from dairy cows. For example, it was revealed that one copy of the myostatin p.F94L leucine allele in beef-on-dairy breeding systems (Limousin/Angus bulls over Jersey/Holstein cows) did not affect gestation length, birth weight, percentage of unassisted births, feedlot average daily gain, live weight at harvest, hot carcass weight, or dressing percentage, but did result in lower marbling scores and increased muscularity, as evidenced through larger, more beef-shaped rib-eyes, lower USDA yield grades, and greater carcass cutout yields (both boxed beef and retail yields) [59].

In this respect, Lim-Flex® Angus-cross sires are homozygous for the leucine-encoding allele of myostatin p.F94L. The leucine allele was derived from the Limousin breed in this Angus × Limousin cross, and it is claimed that Lim-Flex sires can be used to assist in modifying the phenotype of dairy crossbred calves to resemble more closely that of pure Angus cattle. This results in increased visible muscling in the live animal, causing an alteration in the shape and size of the carcass to meet the specifications required for certification as CAB.

A survey was conducted of 1530 calves in a trial involving 125 farms [60]. The authors revealed that whereas purebred dairy calves are destined almost exclusively for veal production, beef × dairy crossbred calves are also destined for beef production after fattening on either the dairy farm of birth, or by specialised cattle fatteners. In veal production, compared with Belgian Blue-sired calves (taken as the reference, and presumably *MSTN* c.821(del11) heterozygous), Limousin-sired calves had a smaller average daily gain and lighter slaughter and carcass weights, while Simmental-sired calves had a similar growth rate, lighter carcass weights, smaller dressing percentage, and smaller muscularity scores. In the case of young bulls and heifers fattened on the dairy farm of birth, Belgian Blue, Piedmontese, and Limousin-sired calves performed similarly; the only exception was that Piedmontese-sired calves had a greater dressing percentage. Belgian Blue and Limousin-sired calves performed similarly when fattened by specialised beef producers. In both veal and beef production, the effects of dam breed were less important than sire breed.

It also confirmed that the *MSTN* c.821(del11) allele in cattle has benefits when crossed with dairy breeds to produce superior progeny [27]. Cattle with two copies were heavier at birth, leaner, and had a higher proportion of muscle mass than animals with zero or one copy. In contrast, heterozygous cattle were heaviest at weaning and had the highest live weight, whereas animals with zero copies had the highest fat content.

It is also interesting to note that one study has revealed an effect of *MSTN* variation on dairy traits, specifically the amount of milk saturated and unsaturated fatty acid; hence, the pleiotropic effects of myostatin variation may need to be considered [61]. This would be of less importance if dairy cows were mated to beef bulls carrying myostatin variations like p.F94L or c.821(del11), but the variation occurred in New Zealand (NZ) Holstein–Friesian × Jersey-cross cows, and the *MSTN* variation described was in the first intron of the gene [61].

In a recent mating of a homozygous *MSTN* c.821(del11) Angus bull across Holstein–Friesian and Holstein–Friesian × Jersey-cross cows in New Zealand, the progeny have a compelling Angus phenotype (i.e., well-muscled, predominantly black colour, and polled; Figure 1). These cattle were all sired by the Angus bull Pilsbury Chester Brave (The Aberdeen–Angus Cattle Society, Perth, Scotland, UK; Identification Number UK170032 100606), who was a double carrier of *MSTN* c.821(del11). With bulls of this kind, a variety of carcass, growth, and reproductive traits are recorded, and the cows to which he was mated are all recorded in the NZAEL and evaluation scheme (https://www.dairynz.co.nz/animal/breeding-decisions/breeding-worth/, accessed on 15 January 2024), with their breeding worth (BW) index value being based on ten traits of importance to dairy production, including eBVs for gestation length and fertility. In this respect, some confidence can be had that the *MSTN* c.821(del11) allele can be effectively employed in terminal sire use, with the goal of producing dairy-cross calves that can meet CAB guidelines.

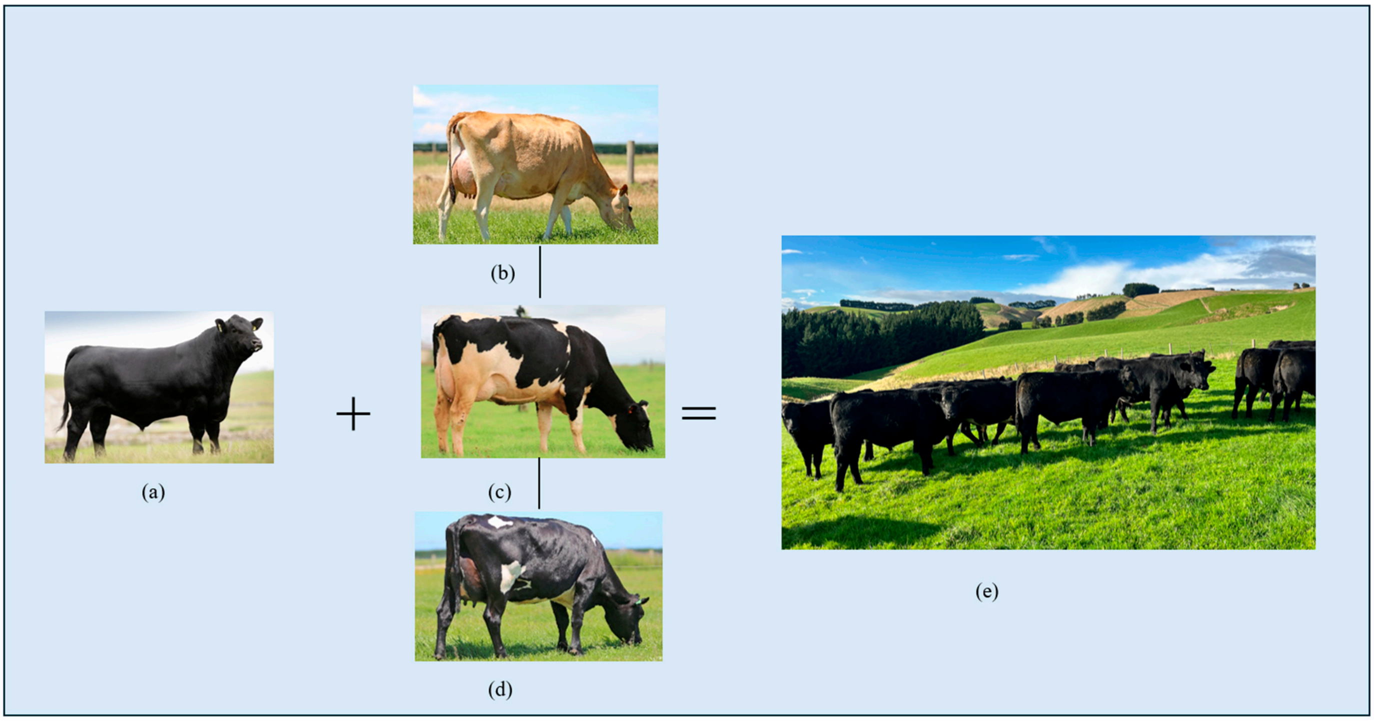

Figure 1. The typical Angus sire (**a**), typical New Zealand Dairy cows (**b** = Jersey, **c** = Friesian, **d** = crossbred) resulting progeny (**e**) from DM angus sire with classic Angus phenotype (solid Black, Polled and beef Phenotype.

6. Climate Benefits of Improved Beef × Dairy Systems

In New Zealand, it has been suggested that a large reduction in GHG emissions could be achieved if surplus calves from the dairy industry were reared for beef production [62]. In this study, it was predicted that dairy beef calves had a 29% lower emission intensity when compared to suckler-beef calves, and that the average emission intensity of beef production could be reduced by up to 22%.

While double-muscled sired progeny from dairy cattle exhibit similar conformation and meat characteristics to beef breed progeny and have high carcass meat yields, this also coincides with a reduced organ mass [35]. Accordingly, voluntary feed intake is decreased, and feed efficiency is improved. The *MSTN* c.821(del11) allele may therefore help reduce GHG gas emissions and nitrogen leaching by reducing intake per kilogram of beef produced.

Climate change benefits and improved livestock production could therefore go hand in hand if double-muscled homozygous *MSTN* c.821(del11) Angus sires were mated to dairy cows. These sires would not only improve meat production from the crossbred progeny, thus allowing a reduction in beef cow numbers to achieve the same amount of quality meat output, but also potentially improve feed efficiency, reducing the GHG footprint per kilogram of meat produced.

However, while dairy-beef systems may offer a reduction in GHG emissions, the role of traditional beef grazing systems, and their contribution to food production on land unsuitable for other purposes like dairy farming, must also be acknowledged. Beef can be produced from extensive, wholly unirrigated range-land systems that are not amenable to dairy farming, or cropping, or that may be unsuitable for producing meat from other smaller ruminants like sheep or goats because of the presence of predators. Additionally, the interconnectedness of milk and beef production systems means that changes in one sector can have implications for the other, which might be positive if, for example, dairy returns were high and meat was low, or vice versa.

7. The Potential for Further Beef × Dairy Development in New Zealand and Globally

The evidence to hand would appear to confirm the benefit of using *MSTN* c.821(del11) homozygous terminal sires for mating to dairy cows, in the quest to obtain progeny with carcasses and meat that meets CAB criteria. These sires could be strategically mated to dairy cows that do not have the genetic merit to be bred from again to produce herd replacements (they have low breeding worth), but that still adds value to the production system with their dairy performance. Their herd counterparts that have genetic merit could then be mated to high genetic merit dairy sires to produce herd replacements, and possibly using sex-selected semen to maximise the number of female dairy-type progeny to select replacements from.

In New Zealand, given that only approximately a quarter of dairy progeny end up as herd replacements [4], as nearly all males and half the females are ultimately culled [63], then potentially only the top half or less of the milking herd would be mated to elite dairy sires, while all the other cows would be mated to dairy sires. At a global level, with an estimated 270 million dairy cattle in the world, albeit many likely filling dual meat and milk production roles, scale-up of the use of beef genetics across dairy cows of lower genetic merit should not only allow the production of more high-quality beef, but also accrue GHG reductions.

While care would need to be taken to ensure there is not an increase in calving difficulties, the contrast between the findings [27,46] would suggest that greater effort needs to be made in dairy production to further improve the birthing performance of dairy cattle. In that respect, it was reported that dystocia rates in dairy cattle internationally are generally <5%, apart from those in the United States, where they are higher [64], while, in contrast, it was reported that New Zealand beef farmers assisted 7% and 1.7% of two- and three-year-old primiparous heifers, respectively [65].

In New Zealand specifically, if the size of the nearly wholly grass-based beef breeding herd (approximately 3.81 million; [66]) was reduced by 500,000 cows, with 90% of the cows producing calves (of which half were female, and perhaps half again of these were needed as replacements), then approximately 375,000 potential finisher beef cattle would be lost per annum. Assuming an average carcass weight of 350 kg at slaughter and a value of NZD 5 per kg of carcass, then a NZD 656 million loss in value may accrue annually.

However, if half the 4.67 million dairy cows in New Zealand produced beef finishing cattle as a consequence of being mated to elite homozygous *MSTN* c.821(del11) Angus bulls, with the same reproductive performance of 90% calves to cows mated, and all the beef calves being finished to 350 kg carcass, then potentially an additional 2.14 million carcasses would be produced, which at NZD 5 per kg would create NZD 3.754 billion of value, a considerable financial gain for the loss of 500,000 beef cows. While potentially more beef cattle could be removed from production, it needs to be acknowledged that these cows serve other purposes, such as grooming overgrown pasture and allowing for the rotational management of sheep to manage parasites. Equally, not all the extensive rangeland where New Zealand beef cattle are farmed is able to support beef finishing systems.

One can only speculate as to what kind of a change to the system this might mean in the context of the global dairy industry.

8. Summary

This review explores the option of using Angus sires mated to dairy cows to produce progeny that produce meat that would meet the CAB standard. It could create a paradigm shift in beef industry practices, especially in countries like New Zealand where nearly all beef and dairy production occurs outdoors on pasture. With the right genetics, including the use of homozygous *MSTN* c.821(del11) Angus bulls, a further gain in cattle GHG efficiency could be obtained, with this improving the already low-GHG New Zealand dairy production system. Adopting a beef-on-dairy breeding strategy may also offer a resilient approach to combatting volatility in both meat and milk prices. This strategy is particularly relevant for New Zealand's predominantly pasture-based farming systems.

By diversifying yields, farmers could better manage market fluctuations, leading to more integrated and sustainable livestock production systems. Overall, this review suggests that such innovations could significantly impact current beef industry practices, contributing to more sustainable farming.

The main objectives and future ideas of this review include emphasizing the importance of specific genetic strategies in improving GHG efficiency, promoting sustainable farming practices, and enhancing the economic resilience of farmers through diversified yields. The authors highlight the potential for a shift towards more integrated livestock production systems, which could lead to substantial environmental and economic benefits.

Author Contributions: H.A.N., C.M., H.A., and J.H. contributed to all aspects of this work. Specifically, the contributions are as follows: Conceptualisation, H.A.N., C.M., and H.A.; investigation, H.A.N., C.M., H.A., and J.H.; resourcing, H.A.N., C.M., H.A., and J.H.; writing—original draft preparation, H.A.N., C.M., H.A., and J.H.; writing—review and editing, H.A.N., C.M., H.A., and J.H.; visualization, H.A.N, C.M., H.A., and J.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: Authors Craig Mckimmie and Hamed Amirpour Najafabadi were employed by the company Samen NZ. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

1. Mazzetto, A.M.; Falconer, S.; Ledgard, S. Mapping the carbon footprint of milk production from cattle: A systematic review. *J. Dairy Sci.* **2022**, *105*, 9713–9725. [CrossRef] [PubMed]
2. Creutzinger, K.; Pempek, J.; Habing, G.; Proudfoot, K.; Locke, S.; Wilson, D.; Renaud, D. Perspectives on the management of surplus dairy calves in the United States and Canada. *Front. Vet. Sci.* **2021**, *8*, 661453. [CrossRef] [PubMed]
3. NZ Dairy Statistics 2022–2023, Livestock Improvement Corporation Limited & DairyNZ Limited. Available online: https://www.dairynz.co.nz (accessed on 10 May 2024).
4. Hickson, R.E.; Zhang, I.L.; McNaughton, L.R. Brief communication: Birth weight of calves born to dairy cows in New Zealand. *Proc. N. Z. Soc. Anim. Prod.* **2015**, *75*, 257–259.
5. Norman, H.D.; Hutchison, J.L.; Miller, R.H. Use of sexed semen and its effect on conception rate, calf sex, dystocia, and stillbirth of Holsteins in the United States. *J. Dairy Sci.* **2010**, *93*, 3880–3890. [CrossRef] [PubMed]
6. Holden, S.A.; Butler, S.T. Review: Applications and benefits of sexed semen in dairy and beef herds. *Animal* **2018**, *12*, s97–s103. [CrossRef] [PubMed]
7. USDA. Certified Beef Programs. Agricultural Marketing Service, United States Department of Agriculture, Washington, DC. 2024. Available online: https://www.ams.usda.gov/grades-standards/certified-beef-programs (accessed on 21 July 2024).
8. USDA. Schedule GLA—November 1996 (Revised 2016) USDA Specification for Characteristics of Cattle Eligible for Approved Beef Programs Claiming Angus Influence. 2016. Available online: https://www.ams.usda.gov/sites/default/files/media/LS-SCH-GLA.pdf (accessed on 1 March 2024).
9. Siebert, J.W.; Jones, C.A. Case study on building the Certified Angus Beef® brand. *Int. Food Agribus. Manag. Rev.* **2013**, *16*, 195–208.
10. Olson, K. CAB's Impact on Beef Quality Standards. *J. Anim. Sci.* **2008**, *86*, 367–375.
11. Albertí, P.; Panea, B.; Sañudo, C.; Olleta, J.L.; Ripoll, G.; Ertbjerg, P.M.; Christensen, P.M.; Gigli, S.; Failla, S.; Concetti, S.; et al. Live weight, body size and carcass characteristics of young bulls of fifteen European breeds. *Livestock Sci.* **2008**, *114*, 19–30. [CrossRef]
12. Klungland, H.; Våge, D.I.; Gomez-Raya, L.; Adalsteinsson, S.; Lien, S. The role of melanocyte-stimulating hormone (MSH) receptor in bovine coat color determination. *Mamm. Genome* **1995**, *9*, 636–639. [CrossRef]
13. Joerg, H.; Fries, H.R.; Meijerink, E.; Stranzinger, G.F. Red coat color in Holstein cattle is associated with a deletion in the MSHR gene. *Mamm. Genome* **1996**, *4*, 317–318. [CrossRef]
14. Rouzaud, F.; Martin, J.; Gallet, P.F.; Delourme, D.; Goulemot-Leger, V.; Amigues, Y.; Ménissier, F.; Levéziel, H.; Julien, R.; Oulmouden, A. A first genotyping assay of French cattle breeds based on a new allele of the extension gene encoding the melanocortin-1 receptor (Mc1r). *Genet. Sel. Evol.* **2000**, *32*, 511–520. [CrossRef] [PubMed]

15. Adams, N.J.; Smith, G.C.; Carpenter, Z.L. Performance, carcass and palatability characteristics of longhorn and other types of cattle. *Meat Sci.* **1982**, *7*, 67–79. [CrossRef]
16. Sexten, A.K.; Krehbiel, C.R.; Dillwith, J.W.; Madden, R.D.; McMurphy, C.P.; Lalman, D.L.; Mateescu, R.G. Effect of muscle type, sire breed, and time of weaning on fatty acid composition of finishing steers. *J. Anim. Sci.* **2012**, *90*, 616–625. [CrossRef] [PubMed]
17. Miguel, G.Z.; Faria, M.H.; Roca, R.O.; Santos, C.T.; Suman, S.P.; Faitarone, A.B.G.; Delbem, N.L.C.; Girao, L.V.C.; Homem, J.M.; Barbosa, E.K.; et al. Immunocastration im-proves carcass traits and beef color attributes in Nellore and Nellore x Aberdeen Angus crossbred animals finished in feedlot. *Meat Sci.* **2014**, *96*, 884–891. [CrossRef]
18. Garcia-de-Siles, J.L.; Ziegler, J.H.; Wilson, L.L. Prediction of beef quality by three grading systems. *J. Food Sci.* **1977**, *42*, 711–715. [CrossRef]
19. Knapp, R.H.; Terry, C.A.; Savell, J.W.; Cross, H.R.; Mies, W.L.; Edwards, J.W. Characterization of cattle types to meet specific beef targets. *J. Anim. Sci.* **1989**, *67*, 2294–2308. [CrossRef]
20. Perry, R.C.; Corah, L.R.; Cochran, R.C.; Beal, W.E.; Stevenson, J.S.; Minton, J.E.; Simms, D.D.; Brethour, J.R. Influence of dietary energy on follicular development, serum gonadotropins, and first postpartum ovulation in suckled beef cows. *J. Anim. Sci.* **1991**, *69*, 3762–3773. [CrossRef] [PubMed]
21. Bass, P.D.; Scanga, J.A.; Chapman, P.L.; Smith, G.C.; Belk, K.E. Associations between portion size acceptability of beef cuts and ribeye area of beef carcasses. *J. Anim. Sci.* **2009**, *87*, 2935–2942. [CrossRef]
22. Lundeen, T. The Challenges of Using Holstein Steer Carcasses in the Restaurant Industry. *Meat Sci.* **2008**, *79*, 641–646.
23. McPherron, A.C.; Lawler, A.M.; Lee, S.J. Regulation of skeletal muscle mass in mice by a new TGF-beta superfamily member. *Nature* **1997**, *387*, 83–90. [CrossRef]
24. McPherron, A.C.; Lee, S.J. Double muscling in cattle due to mutations in the myostatin gene. *Proc. Natl. Acad. Sci. USA* **1997**, *94*, 12457–12461. [CrossRef] [PubMed]
25. Grobet, L.; Royo Martin, L.; Poncelet, D.; Pirottin, D.; Brouwers, B.; Riquet, J.; Schoeberlein, A.; Dunner, S.; Ménissier, F.; Massabanda, J.; et al. A deletion in the bovine myostatin gene causes the double–muscled phenotype in cattle. *Nat. Genet.* **1997**, *17*, 71–74. [CrossRef] [PubMed]
26. Bellinge, R.H.; Liberles, D.A.; Iaschi, S.P.; O'brien, P.A.; Tay, G.K. Myostatin and its implications on animal breeding: A review. *Anim. Genet.* **2005**, *36*, 1–6. [CrossRef] [PubMed]
27. Ryan, C.A.; Purfield, D.C.; Naderi, S.; Berry, D.P. Associations between polymorphisms in the myostatin gene with calving difficulty and carcass merit in cattle. *J. Anim. Sci.* **2023**, *101*, skad371. [CrossRef]
28. Sellick, G.S.; Pitchford, W.S.; Morris, C.A.; Cullen, N.G.; Crawford, A.M.; Raadsma, H.W.; Bottema, C.D. Effect of myostatin F94L on carcass yield in cattle. *Anim. Genet.* **2007**, *38*, 440–446. [CrossRef] [PubMed]
29. Esmailizadeh, A.K.; Bottema, C.D.; Sellick, G.S.; Verbyla, A.P.; Morris, C.A.; Cullen, N.G.; Pitchford, W.S. Effects of the myostatin F94L substitution on beef traits. *J. Anim. Sci.* **2008**, *86*, 1038–1046. [CrossRef] [PubMed]
30. Lines, D.S.; Pitchford, W.S.; Kruk, Z.A.; Bottema, C.D. Limousin myostatin F94L variant affects semitendinosus tenderness. *Meat Sci.* **2009**, *81*, 126–131. [CrossRef] [PubMed]
31. Konovalova, E.; Romanenkova, O.; Zimina, A.; Volkova, V.; Sermyagin, A. Genetic variations and haplotypic diversity in the myostatin gene of different cattle breeds in Russia. *Animals* **2021**, *11*, 2810. [CrossRef] [PubMed]
32. Wheeler, T.L.; Shackelford, S.D.; Koohmaraie, M. Variation in gelatinization and fragmentation of myostatin mutant cattle and its effects on beef tenderness. *Meat Sci.* **2001**, *59*, 33–39.
33. Cafe, L.M.; Hennessy, D.W.; Hearnshaw, H.; Morris, S.G. Effects of the myostatin gene on beef production efficiency. *Aust. J. Exp. Agric.* **2006**, *46*, 183–190.
34. Gill, P.; Smith, S.; Wilkinson, S. Genomic and phenotypic analysis of myostatin-deficient Angus cattle in Scotland. *Genet. Sel. Evol.* **2009**, *41*, 22.
35. Fiems, L.O. Double muscling in cattle: Genes, husbandry, carcasses and meat. *Animals* **2012**, *2*, 472–506. [CrossRef] [PubMed]
36. Menezes, G.R.; Souza, C.B.; Lima, A.; Gondo, A.; Siqueira, F.; Egito, A.A.; Silva, L.N.; Junior, J.A.; Júnior, R.A. 629. Effect of one copy of nt821 mutation in myostatin gene on ultrasound carcass traits in Senepol cattle. In Proceedings of the 12th World Congress on Genetics Applied to Livestock Production (WCGALP), Wageningen, The Netherlands, 9 February 2022; pp. 2601–2604.
37. Robinson, D.L.; Café, L.M.; McKiernan, W.A. Heritability of muscle score and genetic and phenotypic relationships with weight, fatness and eye muscle area in beef cattle. *Anim. Prod. Sci.* **2014**, *54*, 1443–1448. [CrossRef]
38. Cafe, L.M.; McKiernan, W.A.; Robinson, D.L. Selection for increased muscling improved feed efficiency and carcass characteristics of Angus steers. *Anim. Prod. Sci.* **2014**, *54*, 1412–1416. [CrossRef]
39. Cafe, L.M.; Polkinghorne, R.; Robinson, D.L. Increased muscling and one copy of the 821 del11 myostatin mutation did not reduce meat quality in Angus steers. In Proceedings of the 33rd Biennial Conference of the Australian Association of Animal Science, Fremantle, Perth, Australia, 1–3 February 2021; Volume 33.
40. Wiener, P.; Smith, J.A.; Lewis, A.M.; Woolliams, J.A.; Williams, J.L. Muscle-related traits in cattle: The role of the myostatin gene in the South Devon breed. *Genet. Select. Evol.* **2002**, *34*, 221–232. [CrossRef] [PubMed]
41. Casas, E.; Keele, J.W.; Fahrenkrug, S.C.; Smith, T.P.L.; Cundiff, L.V.; Stone, R.T. Quantitative analysis of birth, weaning, and yearling weights and calving difficulty in Piedmontese crossbreds segregating an inactive myostatin allele. *J. Anim. Sci.* **1999**, *77*, 1686–1692. [CrossRef] [PubMed]

42. Casas, E.; Bennett, G.L.; Smith, T.P.; Cundiff, L.V. Association of myostatin on early calf mortality, growth, and carcass composition traits in crossbred cattle. *J. Anim. Sci.* **2004**, *82*, 2913–2918. [CrossRef] [PubMed]
43. Short, R.E.; MacNeil, M.D.; Grosz, M.D.; Gerrard, D.E.; Grings, E.E. Pleiotropic effects in Hereford, Limousin, and Piedmontese F2 crossbred calves of genes controlling muscularity including the Piedmontese myostatin allele. *J. Anim. Sci.* **2002**, *80*, 1–11. [CrossRef]
44. Vissac, B.; Menissier, F.; Perreau, B. Etude du caractere culard. VII. Croissance et musculature des femelles, desequilibre morphologique au velage. *Ann. Génét. Sél. Anim.* **1973**, *5*, 23–38. [CrossRef] [PubMed]
45. Arthur, P.F.; Makarechian, M.; Price, M.A. Incidence of dystocia and perinatal calf mortality resulting from reciprocal crossing of double-muscled and normal cattle. *Can. Vet. J.* **1988**, *29*, 163–167.
46. Mee, J.F.; Berry, D.P.; Cromie, A.R. Risk factors for calving assistance and dystocia in pasture-based Holstein-Friesian heifers and cows in Ireland. *Vet. J.* **2011**, *187*, 189–194. [CrossRef] [PubMed]
47. Berry, D.P.; Amer, P.R.; Evans, R.D.; Byrne, T.; Cromie, A.R.; Hely, F. A breeding index to rank beef bulls for use on dairy females to maximize profit. *J. Dairy Sci.* **2019**, *102*, 10056–10072. [CrossRef] [PubMed]
48. Hosono, M.; Oyama, H.; Inoue, K. Genetic relationships of calving difficulty with birth measurements and carcass traits in Japanese Black cattle. *Anim. Sci. J.* **2020**, *91*, e13491. [CrossRef] [PubMed]
49. Eriksson, S.; Näsholm, A.; Johansson, K.; Philipsson, J. Genetic relationships between calving and carcass traits for Charolais and Hereford cattle in Sweden. *J. Anim. Sci.* **2004**, *82*, 2269–2276. [CrossRef] [PubMed]
50. Pitt, D.; Sevane, N.; Nicolazzi, E.L.; MacHugh, D.E.; Park, S.D.E.; Colli, L.; Martinez, R.; Bruford, M.W.; Orozco-terWengel, P. Domestication of cattle: Two or three events? *Evol. Appl.* **2018**, *12*, 123–136. [CrossRef] [PubMed]
51. Evershed, R.P.; Payne, S.; Sherratt, A.; Copley, M.S.; Coolidge, J.; Urem-Kotsu, D.; Kotsakis, K.; Özdoğan, M.; Özdoğan, A.E.; Nieuwenhuyse, O.P.; et al. Earliest date for milk use in the Near East and southeastern Europe linked to cattle herding. *Nature* **2008**, *455*, 528–531. [CrossRef] [PubMed]
52. Berry, D.P. Invited review: Beef-on-dairy—The generation of crossbred beef × dairy cattle. *J. Dairy Sci.* **2021**, *104*, 3789–3819. [CrossRef] [PubMed]
53. Davis, R.B.; Fikse, W.F.; Carlen, E.; Poso, J.; Aamand, G.P. Nordic breeding values for beef breed sires used for crossbreeding with dairy dams. In Proceedings of the 2019 Interbull Meeting, Cincinnati, OH, USA, 23–26 June 2019.
54. Hessle, A.; Bertilsson, J.; Stenberg, B.; Kumm, K.; Sonesson, U. Combining environmentally and eco-nomically sustainable dairy and beef production in Sweden. *Agric. Systems* **2017**, *156*, 105–114. [CrossRef]
55. Martín, N.; Coleman, L.; López-Villalobos, N.; Schreurs, N.; Morris, S.; Blair, H.; McDade, J.; Back, P.; Hickson, R. Estimated breeding values of beef sires can predict performance of beef-cross-dairy progeny. *Front. Genet.* **2021**, *12*, 712715. [CrossRef]
56. Foraker, B.A.; Frink, J.L.; Woerner, D.R. Invited review: A carcass and meat perspective of crossbred beef × dairy cattle. *Transl. Anim. Sci.* **2022**, *6*, txac027. [CrossRef]
57. Coleman, L.; Martín, N.; Back, P.; Blair, H.; López-Villalobos, N.; Hickson, R. Low Birthweight Beef Bulls Compared with Jersey Bulls Do Not Impact First Lactation and Rebreeding of First-Calving Dairy Heifers—A Case Study in New Zealand. *Dairy* **2022**, *3*, 87–97. [CrossRef]
58. Williamson, H.R.; Schreurs, N.M.; Morris, S.T.; Hickson, R.E. Growth and carcass characteristics of beef-cross-dairy-breed heifers and steers born to different dam breeds. *Animals* **2022**, *12*, 864. [CrossRef]
59. Waller, B.E.; Garcia, S.R.; Fuerniss, L.K.; Johnson, B.J.; Woerner, D.R.; Wulf, D.M. Effects of the F94L myostatin gene mutation in beef × dairy crossed cattle on muscle fiber type, live performance, carcass characteristics, and boxed beef and retail cut yields. *J. Anim. Sci.* **2023**, *101*, skad324. [CrossRef] [PubMed]
60. Bittante, G.; Negrini, R.; Bergamaschi, M.; Ni, Q.; Patel, N.; Toledo-Alvarado, H.; Cecchinato, A. Pure-breeding with sexed semen and crossbreeding with semen from double-muscled sires to improve beef production from dairy herds: Live and slaughter performances of crossbred calves. *J. Dairy Sci.* **2020**, *103*, 5258–5262. [CrossRef] [PubMed]
61. Haruna, I.L.; Li, Y.; Ekegbu, U.J.; Amirpour-Najafabadi, H.; Zhou, H.; Hickford, J.G.H. Associations between the bovine myostatin gene and milk fatty acid composition in New Zealand Holstein-Friesian × Jersey-Cross cows. *Animals* **2020**, *10*, 1447. [CrossRef] [PubMed]
62. van Selm, B.; de Boer, I.J.; Ledgard, S.F.; van Middelaar, C.E. Reducing greenhouse gas emissions of New Zealand beef through better integration of dairy and beef production. *Agric. Syst.* **2021**, *186*, 102936. [CrossRef]
63. MPI. *Mortality Rates in Bobby Calves 2008 to 2016*; New Zealand Ministry for Primary Industries: Wellington, New Zealand, 2017; Available online: https://www.mpi.govt.nz/law-and-policy/legal-overviews/animal-welfare/animal-welfareregulations/caring-for-bobby-calves/ (accessed on 15 March 2024).
64. Mee, J.F. Prevalence and risk factors for dystocia in dairy cattle: A review. *Vet. J.* **2008**, *176*, 93–101. [CrossRef]
65. Hickson, R.E.; Anderson, W.J.; Kenyon, P.R.; Lopez-Villalobos, N.; Morris, S.T. A survey of beef cattle farmers in New Zealand, examining management practices of primiparous breeding heifers. *N. Z. Vet. J.* **2008**, *56*, 176–183. [CrossRef]
66. Beef+Lamb New Zealand. *Stock Number Survey as at 30 June 2023*; Beef + Lamb New Zealand: Wellington, New Zealand, 2023.