A simulation model of dairy herd conversion to produce A2 milk

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Abstract of a thesis submitted in partial fulfilment of the
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A2 milk is cow's milk containing beta-casein that is exclusively of the A2 type. A2^{TM} milk comes from certified herds in which all cows carry two copies of the A2 allele of the beta-casein gene. There are a number of strategies that farmers can use to create a pure A2 herd. These include the use of semen from certified homozygous A2 bulls, genetic testing of cows and calves to determine the beta-casein allele status, and the use of A2 sexed semen. The rate of herd conversion is also mediated by breeding decisions such as replacement rate, culling rate or artificial insemination of yearlings with A2 semen. Other relevant herd parameters include the incidence of the allele at the start of the conversion process and the level of involuntary culling in the herd. Given these complexities, a time-dependent simulation model was developed to investigate the impact of various decision variables and herd parameters on herd structure and genetic gain. Four alternative conversion strategies were explored based on the assumption of using only A2 semen: (1) non-testing of cows and calves, (2) genetic testing of cows, (3) genetic testing of calves, and (4) genetic testing of both cows and calves. For each generic strategy, a range of additional decision variables were explored, including herd replacement rate, culling rate, artificial insemination of yearlings with A2 semen, and A2 sex-selected semen. Results reported here refer to three herd baseline compositions, with initial A1:A2 allele ratios of 1:1, 2:1 and 1:2. In a non-testing situation, the proportion of homozygous A2 cows increases with a function that is in the early years almost linear, but subsequently becomes curvilinear and asymptotic. Hence, regardless of the initial A1:A2 allele ratio or decision variables, a pure A2 herd will never be achieved. In testing situations, A2 achievement of herd purity typically takes between four and fifteen years depending on specific strategies and herd parameters. In most situations, genetic testing of calves is more efficient than genetic testing of cows. However, maximising the rate of conversion requires genetic testing of both cows and calves, together with artificial insemination of yearlings with A2 semen and with high cow replacement rates. The use of sex-selected semen can

further speed up the process. High replacement rates are only effective if undertaken in conjunction with other specific strategies and in some situations can be counter-productive.

There is potential for reduction in the rate of herd genetic gain if the breeding worth (BW) of the bull team declines as a consequence of the elimination of non-A2 bulls. However, artificial insemination of yearlings with A2 semen and high replacement rates can act to reduce any such reduction in the rate of genetic gain by reducing the generation interval.

Keywords: A2 milk, herd selection, beta-casein, A2 semen, genetic testing.

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Table of Contents

Abstract ii

Acknowledgements iv

Table of Contents v

List of Tables vii

List of Figures viii

Chapter 1 Introduction 1

1.1 Problem statement 3

1.2 Research questions 3

1.3 Structure of the thesis 4

Chapter 2 Review of the literature 5

2.1 Introduction 5

2.2 Casein polymorphism and bioactive peptides 5

2.3 Frequency and distribution of the A1 and A2 alleles 6

2.4 Dairy cattle breeding 8

Chapter 3 Methodology 10

3.1 Introduction 10

3.2 The modelling approach 10

3.3 Computer-simulated model 11

3.3.1 Input data 11

3.3.2 Intermediate calculations 12

3.3.3 Output data 13

3.4 Model verification 13

3.5 Model validation 14

3.5.1 Sensitivity analysis 15

Chapter 4 Scenarios, strategies and outcomes 16

4.1 Introduction 16

4.2 Scenarios 16

4.2.1 Non-testing of cows and calves 17

4.2.2 Genetic testing of cows 17

4.2.3 Genetic testing of calves 17

4.2.4 Genetic testing of both cows and calves 18

4.3 Strategies 18

4.3.1 Variations in the replacement rate and involuntary culling rate 18

4.3.2 Artificial insemination (AI) of yearlings with A2 semen 19

4.3.3 A2 sex-selected semen 19

4.4 Outcomes 20

4.4.1 A2 beta-casein in the milk 20

4.4.2 Herd genetic gain 20

Chapter 5 Findings **21**
5.1 Introduction 21
5.2 The non-testing scenario 21
5.2.1 The impact of replacement rate without genetic testing of animals 21
5.2.2 The impact of artificially mating yearlings to A2 semen without genetic testing of animals 22
5.2.3 The impact of involuntary culling rate without genetic testing of animals 23
5.2.4 The impact of using A2 sexed semen without genetic testing of animals 24
5.3 Progress based on genetic testing of cows 24
5.3.1 The impact of replacement rate based on genetic testing of cows 25
5.3.2 The impact of artificially mating yearlings with A2 semen based on genetic testing of cows 27
5.3.3 The impact of involuntary culling rate based on genetic testing of cows 27
5.3.4 The impact of using A2 sexed semen combined with genetic testing of cows but not genetically testing calves 28
5.4 Progress based on genetic testing of calves 28
5.4.1 The impact of replacement rate based on genetic testing of calves 29
5.4.2 The impact of artificially mating yearlings with A2 semen based on genetic testing of calves 31
5.4.3 The impact of involuntary culling rate based on testing of calves 32
5.4.4 The impact of using A2 sexed semen based on testing of calves 32
5.5 Progress based on genetic testing of the herd, including both cows and calves 33
5.5.1 The impact of replacement rate based on genetic testing of the herd, including cows and calves 33
5.5.2 The impact of artificially mating yearlings with A2 semen based on genetic testing of the herd, including cows and calves 34
5.5.3 The impact of involuntary culling rate based on genetic testing of the herd, including cows and calves 35
5.5.4 The impact of using A2 sexed semen based on genetic testing of the herd, including both cows and calves 36
5.6 A2 beta-casein in the milk 37
5.7 Herd genetic gain 38
5.7.1 The impact of a drop in the average BW of bulls 38
5.8 Combining management scenarios and decision strategies 40

Chapter 6 Discussion and conclusions **42**
6.1 Introduction 42
6.1.1 Farmer strategies 42
6.1.2 A2 beta-casein in the milk 44
6.1.3 The impact on herd BW 45
6.1.4 Summary of key findings 47

References **48**

List of Tables

Table 2-1: Summary of beta-casein allele frequency distribution in selected Western cattle breeds (adapted from EFSA, 2009, pp.20-21) 7
Table 4-1: Initial age structure of Herds A, B, and C 16
Table 5-1: Proportion of A2A2 cows after ten years in three herds with different initial A2A2 proportions (Herd A = 25%; Herd B = 10%; Herd C = 45%) in a non-testing scenario using three (25%, 30% and 35%) replacement rates, artificial insemination of yearlings with A2 semen and a 15% involuntary culling rate 23
Table 5-2: Proportion of A2A2 cows after ten years in three herds with different initial A2A2 proportions (Herd A = 25%; Herd B = 10%; Herd C = 45%) in a non-testing scenario using three (10%, 15% and 20%) involuntary culling rates, optional artificial insemination (AI) of yearlings with A2 semen and a 25% replacement rate 24
Table 5-3: Proportion of A2A2 cows after ten years in three herds with different initial A2A2 proportions (Herd A = 25%; Herd B = 10%; Herd C = 45%) in the scenario of genetic testing of cows using three (25%, 30% and 35%) replacement rates, artificial insemination of yearlings with A2 semen and a 15% involuntary culling rate 27
Table 5-4: Proportion of A2A2 cows after ten years in three herds with different initial A2A2 proportions (Herd A = 25%; Herd B = 10%; Herd C = 45%) in the scenario of genetic testing of cows using three (10%, 15% and 20%) involuntary culling rates, optional artificial insemination (AI) of yearlings with A2 semen and a 25% replacement rate 28
Table 5-5: Proportion of A2A2 cows after ten years in three herds with different initial A2A2 proportions (Herd A = 25%; Herd B = 10%; Herd C = 45%) in the scenario of genetic testing of calves using three (25%, 30% and 35%) replacement rates, artificial insemination of yearlings with A2 semen and a 15% involuntary culling rate 31
Table 5-6: Proportion of A2A2 cows after ten years in three herds with different initial A2A2 proportions (Herd A = 25%; Herd B = 10%; Herd C = 45%) in the scenario of testing of calves using three (10%, 15% and 20%) involuntary culling rates, optional artificial insemination (AI) of yearlings with A2 semen and 25% replacement rate 32
Table 5-7: Time (years) required to achieve a pure A2 herd starting with different initial A2A2 proportions (Herd A = 25%; Herd B = 10%; Herd C = 45%) in the scenario of genetic testing of calves, artificial insemination of yearlings, using A2 sexed semen and four (25%, 30%, 35% and 40%) replacement rates. 33
Table 5-8: Time (years) required to achieve a pure A2 herd starting with different initial A2A2 proportions (Herd A = 25%; Herd B = 10%; Herd C = 45%) in the scenario of genetic testing of cows and calves using three (25%, 30% and 35%) replacement rates, artificial insemination of yearlings with A2 semen and a 15% involuntary culling rate ... 35
Table 5-9: Proportion of A2A2 cows after ten years in three herds with different initial A2A2 proportions (Herd A = 25%; Herd B = 10%; Herd C = 45%) in the scenario of genetic testing of cows and calves using three (10%, 15% and 20%) involuntary culling rates, optional artificial insemination (AI) of yearlings with A2 semen and a 25% replacement rate 36
Table 5-10: Proportion of A2A2 cows after ten years and time (years) to achieve a pure A2 herd for alternative management scenarios, and different initial A2A2 herd proportions (Herd A = 25%, Herd B = 10%, Herd C = 45%) 41

List of Figures

Figure 5-1: Proportion of A2A2 cows over a ten year period in three herds with different initial A2A2 proportions (Herd A = 25%; Herd B = 10%; Herd C = 45%) in a non-testing scenario using three (22%, 25% and 27%) replacement rates (RR), no artificial insemination of yearlings and a 15% involuntary culling rate..... 22
Figure 5-2: Proportion of A2A2 cows over a ten year period in three herds with different initial A2A2 proportions (Herd A = 25%; Herd B = 10%; Herd C = 45%) in the scenario of genetic testing of cows using 22% replacement rate, no artificial insemination of yearlings and a 15% involuntary culling rate..... 25
Figure 5-3: Proportion of A2A2 cows over a ten year period in a herd with initial A2A2 proportion of 25% (Herd A) in the scenario of genetic testing of cows using three (22%, 25% and 27%) replacement rates (RR), no artificial insemination of yearlings and a 15% involuntary culling rate 26
Figure 5-4: Proportion of A2A2 cows over a ten year period in two herds with initial A2A2 proportions (Herd B = 10%; Herd C = 45%) in the scenario of genetic testing of cows using three (22%, 25% and 27%) replacement rates (RR), no artificial insemination of yearlings and a 15% involuntary culling rate..... 26
Figure 5-5: Proportion of A2A2 cows over a ten year period in three herds with different initial A2A2 proportions (Herd A = 25%; Herd B = 10%; Herd C = 45%) in the scenario of genetic testing of calves using a 22% replacement rate, no artificial insemination of yearlings and a 15% involuntary culling rate..... 29
Figure 5-6: Proportion of A2A2 cows over a ten year period in a herd with an initial A2A2 proportion of 25% (Herd A) in the scenario of genetic testing of calves using three (22%, 25% and 27%) replacement rates (RR), no artificial insemination of yearlings and a 15% involuntary culling rate..... 30
Figure 5-7: Proportion of A2A2 cows over a ten year period in two herds with different initial A2A2 proportions (Herd B = 10%; Herd C = 45%) in the scenario of genetic testing of calves using three (22%, 25% and 27%) replacement rates (RR), no artificial insemination of yearlings and a 15% involuntary culling rate..... 31
Figure 5-8: Proportion of A2A2 cows over a ten year period in three herds with different initial A2A2 proportions (Herd A = 25%; Herd B = 10%; Herd C = 45%) in the scenario of genetic testing of cows and calves using three (22%, 25% and 27%) replacement rates (RR), no artificial insemination of yearlings and a 15% involuntary culling rate 34
Figure 5-9: Time (years) required to achieve a pure A2 herd starting with different initial A2A2 proportions (Herd A = 25%; Herd B = 10%; Herd C = 45%) in the scenario of genetic testing of cows and calves using three (25%, 30% and 35%) replacement rates, A2 sexed semen, artificial insemination of yearlings and a 15% involuntary culling rate..... 37
Figure 5-10: Comparison of the proportion of A2 beta-casein in the milk and the proportion of A2A2 cows over a fifteen year period in a herd with an initial A2 allele frequency of 50% (25% A2A2 cows) for a non-testing situation. 38
Figure 5-11: The effect on herd genetic gain (BW units) for alternative scenarios of bull BW loss (20 and 40 units) in a non-testing scenario using only A2 semen, no artificial insemination of yearlings and a replacement rate of 25% (15% involuntary culling rate)..... 39
Figure 5-12: Proportion of A2A2 cows over a ten year period in a herd with an initial A2 allele frequency of 50% (25% A2A2 cows) for alternative decision strategies..... 40

Chapter 1

Introduction

A2^{TM} milk is a premium brand product, in which the beta-casein protein is all of the A2 type. Since 2003, A2 milk has been marketed in both New Zealand and Australia with a demand driven by health conscious consumers (A2 Corporation, 2011). However, the proposition of a healthier alternative to standard milk imposes a numbers of dilemmas. From a health perspective, controversy remains as to whether the alternative A1 beta-casein (which is absent from A2 milk) might negatively affect public health (European Food Safety Authority [EFSA], 2009). From a dairy farmer viewpoint, the issue is whether notice should be taken of positive market signals relating to the A2 milk business and whether a decision should be made to breed for A2 milk production.

The debate around milk proteins as a source of bioactive peptides started at the end of the 1990's. Firstly, Elliot et al. (1999) published scientific evidence, linking the A1 beta-casein variant with an increased incidence of Type 1 diabetes. Later, a trial published by Cade et al. (2000) associated the opioid peptide beta-casomorphin-7 (BCM-7), which is released from A1 beta-casein on digestion (De Noni, 2008) with neurological conditions such as autism and schizophrenia. MacLachlan (2001) correlated death rates from cardiovascular disease with the intake of the A1 beta-casein. Since 2002, further evidence has correlated the A1 beta-casein and the peptide BCM-7 in the etiology of several human illnesses. As examples, it has been cited as being linked to the sudden infant death syndrome (Sun et al., 2003) auto-immune conditions, milk intolerances, mild to severe allergies like asthma and eczema, and Type 2 diabetes (Woodford, 2011).

Although the role of beta-casein variants in regard to public health remains controversial, a growing demand for A2 milk has been observed in Australia. In 2011, sales rose by 32% despite a premium price, reaching a market share by value of 4.2% in the grocery channel (A2 Corporation, 2011). Sales of A2 fresh milk, between 2007 and 2012, exhibit more than a 10-fold growth. In addition, the A2^{TM} Full Cream Milk is within the top 20 SKUs by value in Australian grocery chains, the only dairy product in the top 20 branded SKU[1] (A2 Corporation, 2012b). Latest claims by the A2 Corporation are for a 6.9% share by value of the fresh milk market, with sales growth on the prior year of 57% (A2 Corporation, 2013).

[1] Stock Keeping Units is a code that uniquely identifies a product. It is used by retail stores to keep track of inventory.

The potential for further growth and demand for A2^{TM} dairy products have led to investments and entrepreneurship. In November 2011, the A2 Corporation signed a joint venture agreement with Robert Wiseman Dairies, the largest fresh milk processor and distributor in Great Britain. This sales and marketing agreement introduces the A2 brand milk products to the United Kingdom (UK) and Ireland. Since October 2012, A2 fresh milk is available in nearly 700 grocery shops of three major retailers in Britain (A2 Corporation, 2013).

In March 2012, the A2 Corporation appointed a new milk processing plant in Sydney to meet the growing demand for A2 milk in Australia. In New Zealand, in April 2012, the A2 Corporation announced a supply agreement with Synlait Milk Ltd (A2 Corporation, 2012a). The deal involves using A2 milk from accredited Canterbury suppliers to manufacture A2 milk powders and infant formula at Synlait's processing plant near Rakaia. Later, in October 2012, a distribution agreement was announced with China State Farm Holding Shanghai Company (CSF). Under the agreement, CSF is the exclusive distributor in China of A2 infant formula produced by the Canterbury-based processor (A2 Corporation, 2012b).

At a farm level, Australian dairy farmers producing milk from certified A2 cows receive a premium price of about $NZ 0.50 per kg MS, which ensures a steady supply of new suppliers. In the context of contracted supply, the A2 Corporation pays the cost of genetic testing of cows (K. Woodford, personal communication, January 10th, 2012). In the United States of America (US), some dairy farmers expressed their intention to practice genetic testing of herds for the A2 allele, representing a milestone in the conversion process into A2 milk production in the US (A2 Corporation, 2010).

In New Zealand, a number of farmers are slowly shifting their herds to A2 milk production through a passive approach, which consists of using semen that comes exclusively from certified A2 bulls. The evidence of this has not been formally documented, but it is notable that the two main suppliers of dairy semen have listed the A1/A2 status of top elite bulls. Also, the Ranking of Active Sires (RAS) List and the LIC's Premier Sires DNA and Daughter Proven Bull Teams include high ranking A2A2 bulls (Livestock Improvement Corporation [LIC], 2013). Furthermore, CRV Ambreed sells A2 sex-selected semen, listing the A1/A2 status of the bulls (CRV Ambreed, 2013a).

1.1 Problem statement

Farmers might wish to move toward converting their herds to pure A2 in order to capture a premium price or as a risk management tool (Woodford, 2007). Whichever the reason, a conversion process is likely to impact on the bio-economic performance of the dairy farm. Financial components, including the cash costs associated with genetic testing of the herd and selection, and opportunity costs due to the potential for reduced genetic progress and variations in the age structure of herds, are important factors in developing a breeding program. Regardless of the chosen strategy, there will be time lags between decisions and results. In addition, herd management decisions, including herd splitting, separate milk collections and recording systems, need careful planning.

The aim of this research is to explore the impact of alternative breeding strategies and their associated conversion outcomes. The farm decision problem focuses on the rate of herd conversion (measured as the proportion of A2A2 cows) and the costs related to herd improvement (measured as Breeding Worth). Thus, this is a specific investigation within a broader range of animal breeding decision issues where farmers make choices that have cash costs and opportunity costs and that have delayed outcomes.

1.2 Research questions

Given the problem statement, this thesis has one main research question that forms the core of this research. At the same time, it also has a few complementary questions which will contribute to a much better understanding of the main research questions.

The primary research question of this study is:

- What is the expected speed of conversion to A2 in different scenarios, assuming alternative breeding strategies?

The contributory questions of this thesis are:

- What is the impact of different replacement rates and culling rates?
- What is the impact of artificially mating yearlings with A2 semen?
- What is the impact of using A2 sex-selected semen?
- What is the cost of conversion in terms of Breeding Worth (BW)?

1.3 Structure of the thesis

The thesis is divided into six chapters. This first chapter has introduced the research, covering an overview of the research problem and also the research questions that the thesis answers at the conclusion of this research. In addition, it includes the structure of the thesis chapter by chapter.

Chapter two covers the review of literature, which is mainly focused on casein polymorphism, the role of bio-active peptides, and the allele distribution amongst dairy breeds. The last part of the chapter covers aspects associated with cattle breeding, in the context of dairy farming systems in New Zealand.

Chapter three is about methodology, explaining the modelling approach and the stages required for developing the model. It also explains both the key parameters and the decision variables. Finally, how the model was verified and validated is described.

As different scenarios are relevant for this research, chapter four provides an overview of the simulated scenarios, and alternative breeding strategies that can be used during a conversion process. The purpose of this chapter is to outline the expected outcomes and the reasoning behind those decisions.

Chapter five presents the main findings of this research. In total, four main scenarios were simulated. In each scenario, three herds are compared starting from a different initial A1:A2 allele ratio, but using the same key parameters and decision variables. The second part of the chapter explores the A2 beta-casein in the milk, and the costs related to herd genetic gain. The last part of the chapter provides a summary of specific breeding decisions and its effect on the rate of herd conversion.

Finally, chapter six is a critical analysis based on the outcomes obtained in the simulation phase. A range of farmer strategies and herd breeding decisions are analysed in order to shape the answers to the main research question as well as the complementary questions. At the end of the chapter, a section summarises key findings and the main conclusions of this research.

Chapter 2

Review of the literature

2.1 Introduction

This chapter reviews several topics that shape this research. First, the review covers the significance of casein polymorphism and bio-active peptides with emphasis on the key principles for selection of the A2 allele of the beta-casein gene. Second, the chapter provides a review of the beta-casein allele frequency of the genus *Bos taurus* and *Bos indicus*. Finally, the chapter provides an overview of particular characteristics in dairy cattle breeding, in a New Zealand context, which shapes the foundations of this thesis.

2.2 Casein polymorphism and bioactive peptides

Caseins represent the major protein fraction in cow's milk (Silva & Malcata, 2005). They are classified into four types: (1) alpha s^1, (2) alpha s^2, (3) beta, and (4) kappa-casein (Cozma et al., 2011). Amongst these, beta-casein is of particular interest because it is the precursor of opioid peptides (EFSA, 2009). These biologically active peptides are hidden in an inactive form within the sequence of the parent protein, but can be liberated from the dairy products by enzymatic degradation (De Noni & Cattaneo, 2010).

There are at least 12 genetic variants of beta-casein: A1, A2, A3, B, C, D, E, F, G, H1, H2, and I (Kaminski et al., 2007). The beta-casein status of cows is genetically encoded; as a result every cow can be subject to selection according to her casein genes (Morris et al., 2005). In dairy cattle, the A1 and A2 are the most frequent alleles (Olenski et al., 2010). Investigations on cattle phylogeny indicate that the A2 variant is the original beta-casein, while the A1 variant is the result of a genetic variation that occurred thousands of years ago affecting some cattle of European origin (Bradley et al., 1998).

The A1 and A2 genetic variants differ in one amino acid of the polypeptide chain that contains a sequence of 209 residues. The A2 form contains proline at position 67, whereas in the A1 form, proline has been substituted with histidine (Ginger & Grigor, 1999). This amino acid substitution affects the proteolysis of the protein primary structure, leading to cleavage of different peptides as the result of gastrointestinal digestion by enzymes (De Noni, 2008; EFSA, 2009).

Using in vitro digestion of beta-casein, Jinsmaa and Yoshikawa (1999) found that pancreatic elastase breaks down the peptide bond between Ile^{66} and His^{67}, releasing a protein fragment termed beta-casomorphin-7 (BCM-7). Importantly, this type of hydrolysis occurs in the A1 variant, whereas in the A2, the stronger bond Ile^{66}-Pro^{67} does not cleave, releasing BCM-9 instead of BCM-7. According to Woodford (2010, p.81) the peptide BCM-9 differs from BCM-7 not only in the size of the molecule, but also in its biological properties. The BCM-7 is a smaller molecule, which can more easily enter the bloodstream, and has stronger opioid effects.

The release of BCM-7 from the less common genetic variants follows the same pattern, according to their amino acid sequence (Woodford, 2010, p.39). Thereby, beta-casein variants B, C, and F that have histidine at position 67 are likely to release BCM-7. This does not occur in variants A3, D and E, which have proline at position 67. Jinsmaa and Yoshikawa (1999) found that the enzymes pepsine and leucine aminopetidase break down the bond Leu^{58}-Val^{59} in the amino acidic sequence, and finally remove valine from the N terminus of the peptide. As a consequence, the peptide´s full structure of seven amino acids is released in the intestine, therefore increasing morphine-like activity in the body.

The primary sequence of the A1 and A2 protein variants is encoded by a pair of genes located on bovine chromosome six, which have a co-dominant and additive effect (Rijnkels, 2002 as cited in Kaminski, 2007). As every cow receives one gene from each progenitor in a 1:1 ratio, that is, two copies of the beta-casein gene, there are three possible genotypes: the homozygous A1A1 and A2A2, and the heterozygous A1A2 (Woodford, 2007). As a consequence, the progeny resulting from homozygous A2 dams mated with homozygote A2 sires will be invariably A2A2.

2.3 Frequency and distribution of the A1 and A2 alleles

The beta-casein allele frequency distribution varies between breeds of cows, and strains thereof, leading to considerable frequency variations between geographic locations (Kaminski et al., 2007). The occurrence of genetic variants over a 40 year-period within *taurine* breeds, has been comprehensively summarized by the European Food Safety Authority (2009, Table 5, pp. 20-21). The report focuses on the most common protein variants, A1, A2, and B.

Table 2-1: Summary of beta-casein allele frequency distribution in selected Western cattle breeds (adapted from EFSA, 2009, pp.20-21)

Breed	No. Animals	β-Casein Allele Frequency				Reference
		A1	A2	B	Other	
Ayrshire	45 (USA)	0.72	0.28			Kiddy et al., 1966
Ayrshire	29 (UK)	0.6	0.4			Aschaffenburg, 1968
Ayrshire	? (CAN)	0.6	0.4			Ng-Kwai-Hang and Kim, 1994
Ayrshire	37 (NZ)	0.432	0.527			Winkelman and Wickham, 1997
Ayrshire	20,990 (FIN)	0.509	0.49	0.001		Ikonen et al., 1996
Ayrshire	46 (FIN)	0.5	0.5			Lien et al., 1999
Holstein	260 (AUS)	0.63	0.35	0.02		McLean et al., 1984
Holstein	1383 (ITA)	0.58	0.4	0.02		Aleandri et al., 1997
Holstein	1152 (USA)	0.43	0.55	0.02		Van Eenennaam and Medrano, 1991
Holstein-Fr	85 (UK)	0.66	0.24	0.06	A3:0.04	Aschaffenburg et al., 1968
Holstein-Fr	87 (GER)		0.96	0.04		Aschaffenburg et al., 1968
Holstein-Fr	6460 (CAN)	0.54	0.44	0.01	A3:0.01	Hines et al., 1977
Holstein-Fr	6575 (USA)	0.42	0.53	0.02	A3:0.03	Hines et al., 1977
Holstein-Fr	260 (USA)	0.624	0.347	0.025	A3:0.004	McLean et al., 1984
Holstein-Fr	920 (CAN)	0.363	0.632	0.001	A3:0.004	Lin et al., 1986
Holstein-Fr	696 (IRE)	0.72	0.25	0.03		O' Hara, 1995
Holstein-Fr	43 (FIN)	0.43	0.523	0.047		Lien et al. 1999
Holstein-Fr	143 (POL)	0.402	0.598			Kaminski et al., 2007
Guernsey	196 (USA)	0.01	0.98	0.02		Aschaffenburg, 1963
Guernsey	40 (USA)		0.96		C:0.04	Van Eenennaam and Medrano, 1991
Jersey	37 (USA)	0.22	0.49	0.29		Kiddy et al., 1966
Jersey	47 (UK)	0.09	0.63	0.28		Aschaffenburg, 1968
Jersey	308 (AUS)	0.07	0.57	0.36		McLean et al., 1984
Jersey	157 (DEN)	0.07	0.58	0.35		Bech and Kristiansen, 1990
Jersey	172 (USA)	0.17	0.5	0.33		Van Eenennaam and Medrano, 1991
Jersey	? (CAN)	0.19	0.5	0.31		Ng-Kwai-Hang and Kim, 1994
Jersey	116 (IRE)	0.3	0.41	0.28	A3:0.01	O' Hara, 1995
Jersey	1328 (NZ)	0.123	0.591			Winkelman and Wickham, 1997

In Ayrshire cattle, the A1 variant slightly predominates, whereas in the Holstein-Friesians the A1 and A2 variants occur at approximately equivalent allele frequency. The B allele, largely absent in Ayrshire cows, is also barely present in the Holstein-Friesian breed. Conversely, in Guernsey cattle the predominance of the A2 variant is remarkable at 96% to 98%. In the Jersey breed the A1 allele has a moderately low frequency and the A2 allele occurrence is about 50%, but the B allele has a relatively high frequency (Table 2.1). These results are consistent with a previous review by Kaminski et al. (2007).

In addition, geographically related frequencies of alleles amongst countries have been proposed as a result of selective breeding, influencing milk production traits due to both natural and artificial selection (EFSA, 2009, pp. 20-23). In Iceland, Iggman et al. (2003) compared milk samples from Nordic countries. They reported a higher frequency of the A2 allele in Icelandic milk compared to cow's milk from Denmark, Finland or Sweden. This was attributed to geographical isolation, and to the less intense use of European bloodlines in breeding programs.

Few studies have measured the presence of beta-casein A1 and A2 alleles in *Bos indicus* cattle. Mishra et al. (2009) published the first report about the frequency of these protein variants in Indian livestock, including Zebu and river buffalo breeds. They reported that Zebu cattle have a very high occurrence of the A2 allele (98.7%) while buffaloes are exclusively of A2 genotype.

2.4 Dairy cattle breeding

Breeding programmes are useful tools for genetic selection of specific types of milk proteins (Holmes et al., 2007, p.181). A number of mating strategies for moving toward the genotype A2A2 includes: (1) maximising the use of A2A2 sires in a breeding programme (Smiltina et al., 2010); (2) genetic testing of herds to allow selective culling of cows, and calf retention (Woodford, 2010, p.160); (3) high replacement rates; and (4) the use of sex-selected semen to speed up the conversion process (Woodford, 2007).

In New Zealand, genetic progress is one of the keys to improving the economic efficiency on dairy farms (Harris, 2005). The Animal Evaluation System introduced in 1996 is a benchmarking tool for comparing the daughters of different sires, and between different dams. The overall objective is to identify the most efficient converters of feed into profit (Animal Evaluation Unit [AEU], 2009). The system is based on a number of traits, which are used to calculate the economic values or indexes. In particular, the Breeding Worth (BW) index measures the expected ability of dams and sires to breed profitable and efficient progeny. As an index of profit, the BW is expressed as the extra dollars income per year compared to the average cow of a specified baseline year (with this baseline year being periodically brought forward), per 4.5 tonnes of Dry Matter (DM) eaten annually.

The relative efficiency of dairy farms can be improved by selection and crossbreeding. The average farm production costs can decrease by breeding more efficient cows which optimise milk solid production per hectare (Lopez-Villalobos et al., 2000). There is evidence that suggests that the A2 allele has a positive influence on breeding values for milk protein yield, but a negative effect on fat percentage content (Olenski et al., 2010).

According to Morris et al. (2005) there is a positive correlation between the A2 allele and the breeding worth (BW) of cows. They calculated the net income per cow according to their genotype, obtaining a surplus of $15.80 in favour of A2A2 cows. The reported results were obtained using the economic values of milk components in the Breeding Worth formula for 2004.

Culling decisions on-farm can have an important effect on the economic performance of the dairy farm. Rearing heifer replacements represents a major operational cost for dairy farmers (Hadley et al., 2006). A common culling strategy is to replace cows of low Production Worth (PW) with heifers of higher genetic merit as a way to increase profits. However, an increase in the culling rate may have a negative economic effect due to increased rearing costs and/or low stock prices that can exceed the production gains (Vollebregt, 1998).

High replacement rates can decrease potential milk production, because young heifers produce less milk than older cows. In New Zealand, the two-year-old heifer produces about 23% less than the four to eight-year-old cows, while the three-year-old heifer produces 10% less compared to the same group (DairyNZ, 2012). Increasing the stocking rate can compensate for the lower milk production in herds with a higher proportion of first-calving heifers, given the lower annual feed requirements (megajoules of metabolizable energy) for maintenance and production of the two-year-old heifers.

Chapter 3

Methodology

3.1 Introduction

This chapter describes, step by step, the process of building the model. First, an overview is provided of the modelling approach, followed by a description of the model itself. This includes the three sections of the model comprising input data, intermediate calculations and output data. Second, model verification and validation are discussed. The last part of the chapter refers to sensitivity and scenario analysis.

3.2 The modelling approach

The methodology is a system simulation of cattle breeding and selection strategies, investigating the impact over time of various decision criteria on herd structure, together with the expected impact on Breeding Worth (BW). The initial models represent a range of existing situations under different baseline assumptions, with projections of future scenarios then investigated under alternative decision structures. The overall goal is a predictive model for conditions at a future time, with emphasis on how decisions might cause changes in the behaviour of the system. The model uses time steps that are annual. In essence, the project investigates herd structure and BW through a dynamic (time related) model for a range of alternative breeding decisions, and measures the impact on the herd conversion process of four key categories of management decisions.

The model is a simplified representation of reality, as it is not possible to simulate every aspect of the dynamic complexity of real farming systems. In this context, a set of deterministic assumptions has been assumed although in real world situations these are probabilistic events. For instance, model parameters such as the expected (50%) male to female calving rate (or 90% using A2 semen) as well as the expected ratio (1:1) of A1A2 and A2A2 calves from mating A1A2 cows with A2 semen are fixed values which are assumed for all seasons. In practice, the likelihood of occurrence for these events in consecutive years is uncertain, and natural phenomena result in a skewed distribution. Further simplifications include the BW values, which are a fixed value for each age group, without considering the normal distribution of a cow's genetic merit within an age group.

3.3 Computer-simulated model

A computer-simulation model was developed based on livestock reconciliations, using Microsoft Excel. The worksheet contains three subsections; input data, intermediate calculations and output data. Most of the input data from the model is numeric, however, some criteria on herd breeding policy are stated with words rather than numbers. For instance, key decision variables such as whether to use genetic testing over the herd, whether to mate yearlings by artificial insemination (AI), and whether to use sex-selected semen require a 'yes or no' answer. All intermediate calculations and output data are numeric.

3.3.1 Input data

The input data section includes both key parameters and decision variables that are used when making decisions about herd conversions. Importantly, all parameters and decision variables are user-determined. The key parameters are:

- The initial A1/A2 ratio: this determines the starting proportion of A1A1, A1A2, and A2A2 cows in the herd.
- Milking herd size: this determines the total number of lactating cows.
- Expected herd size variation: this is the percentage of growth or contraction in the milking herd size. A decision is made in growth or contraction at the start of the conversion process and that decision has a time lag of two years, before there is any impact on milking herd numbers. From the third year, the herd size will not vary.
- Replacement rate: the percentage of replacement heifers introduced to the herd each year.
- Death rate: the percentage of annual deaths. This rate is set up by age group.
- Involuntary culling rate: the percentage of cows and calves that have to be culled for reasons other than their genotype including diseased, aged and empty cows. This rate is set up by age group.
- Age structure: the initial percentage of each age group in the herd, from yearlings to ten-year-old cows.
- Purchases: the number of A2A2 yearlings and/or cows bought to increase herd size or speed up the process. Purchases are only allowed in year one.

- Breeding Worth: the average genetic merit of dams and sires at the start of the simulation. In line with historical data for New Zealand conditions, the initial bull BW (user-determined) is assumed to increase thereafter for all scenarios at ten units each year.

The decision variables include:

- Genetic testing: whether or not cows and/or calves are to be tested.
- Yearlings to A2 semen: whether or not yearlings are artificially inseminated and hence are a potential source of A2 progeny.
- Sex-selected semen: whether or not A2 sexed semen is used.

The model can be run using a combination of different parameters and decision variables. In this research the model is implemented to explore a range of scenarios that might optimise the conversion process of herds to pure A2.

3.3.2 Intermediate calculations

A number of intermediate calculations were used mainly, to avoid circular references in the spreadsheet. These include the average BW of cows and calves, the total number of cows and yearlings wintered per year, and the total number of cows and yearlings culled for voluntary reasons. All tables in this section are linked to decision variables in the input data section, which determines discretional model behavior given by the 'yes or no' answers.

An example is the manner in which cows are culled. If cows have been tested, the model first sells cows from the A1A1 group, following by the A1A2, and A2A2 respectively. In contrast, if the A1/A2 status is unknown, cows are sold based on age, at equal percentage in each sub-herd. This criterion doesn't apply to ten-year-old cows, as all of them are sold at the end of the season regardless of genotype.

The genetic merit of the herd (measured as BW) is estimated by weighting the BW of each age group in each sub-herd (A1A1, A1A2, A2A2) by the number of animals in that category. The genetic merit of offspring is the mean of the BW of the parents. The loss of bull BW as a consequence of using exclusively A2 semen is user-determined, and the consequence of this loss will then flow through to the model-determined herd BW for future years.

Given that rising two-year-old cows (mated at 15 months) will have a higher BW than older cows in the herd, the decision as to whether or not to artificially inseminate these heifers and select their progeny as future herd replacements will impact on future herd BW. This effect is captured in the model.

3.3.3 Output data

The output data section contains the outcome values of a given herd, assuming a range of parameters and decision variables. The information is allocated for each of the three sub-herds, each table representing a yearly summary of changes on herd structure. In this model the basic livestock reconciliation equation for any age class is:

Opening Numbers + Purchases + Births – Deaths – Culling – Sales = Closing Numbers

Closing numbers in year 'n' become opening numbers in year 'n+1'. Likewise, when closing numbers become the opening numbers for the following year, the age class is increased; that is, the next year is an age class older. Following the same logic, opening numbers in year 'n', plus or minus the expected variation (%) in the milking herd size, must be equal to opening numbers in year 'n+1'. In this equation, culling refers to the involuntary culling while sales refer to the surplus for sale as voluntary culling.

The time lag between the initial breeding decisions and outcomes thereof depends both on the fundamental biology and when during the year the decision is made to convert the herd. At least two years and nine months are required from conception before the A2A2 progeny start producing any milk. In this research, time is reported in full years, and it is thereby assumed that the first calves to A2 semen are born a year after the herd conversion decision. As a consequence, if the results reported here indicate, for example, the percentage of A2A2 cows after 'x' years, this means 'x' years after the herd conversion decision, and 'x-1' years after the first calves to A2 semen are born.

3.4 Model verification

The verification phase has two main objectives: (1) to ensure that the model is mathematically accurate, and (2) to ensure that the model is free from logical errors. Recognising that debugging a model can be a tough, frustrating and time-consuming task, an error-prevention strategy was adopted which includes the following verification techniques:

• Progressive development process: the model was built sequentially, starting with the simplest version before adding the next level of complexity.

• Backup files: a folder was kept with files containing the previous versions of the model. The purpose was to allow comparative analysis of model runs as a way of determining the circumstances where an error may or may not have occurred.

• Master copy: there was only one master copy of the model, where changes could be made.

• Model documentation: a system used for reporting errors, recording changes and suggestions to the model. This provided clarity as to the specific conditions and assumptions associated with each updated version.

3.5 Model validation

The validation phase of modelling is the process of deciding whether a model is effective or suitable for a specific purpose. As this dilemma might not have an absolute answer, model validation is in essence subjective. In this research, the model intends to capture the key conditions of dairy farming systems in New Zealand, specifically in aspects such as BW, calving rate and replacement rate, age structure of the herd, the A1/A2 allele distribution in the herd, culling rate and death rate.

As an example, this model utilises the indexes provided by the Animal Evaluation Unit (AEU). Within the Animal Evaluation Indexes, the BW is used to guide breeding decisions. Importantly, the BW model is constructed for New Zealand conditions, in which the weightings used for breeding values for milk protein, fat content, and/or milk volume are different from the weightings used overseas. Although the general genetic principles may be very similar, it is likely that any other international Animal Evaluation System would focus on different parameters.

In practice, validation cannot be proven with absolute certainty. In this case, model validation was assessed through some of the following techniques: (1) comparing simulated data with recorded data from the information systems of real dairy farms; (2) comparing simulated results with average results reported in national statistics; (3) involving a third party who examined the assumptions, who checked the calculations and who questioned the logic of the model; and finally (4) through sensitivity analysis.

3.5.1 Sensitivity analysis

Sensitivity analysis is a validation technique which allows observation of how the model reacts to changes in it. In this research, it was conducted to quantify the relationships between a set of parameter values and decision variables, and the information from the output data section. Sensitivity analysis is a useful technique for estimating in which range acceptable results are obtained, and which allows the setting of boundaries such as the maximum replacement rate or culling rate. A common approach for testing the model was to input different parameters or variables and ascertain whether the model could calculate sensible results.

A better understanding of the equation y = bx + c may help to illustrate the relationship between parameters and variables. In this equation, 'y' is an output (dependent) variable, 'x' is an input (independent) variable, whereas 'b' and 'c' are parameters of the model. In this context, a dependent variable may be closing numbers at the end of each year, and the independent variable may be the initial numbers by age class. As previously stated, b is a parameter; for example, the effective calving rate that links the input and output variables. In a real world situation, there are biological parameters such as death rate, involuntary culling rate and/or conception rate which the farmer does not have full control over. However in the model, these biological parameters have been assumed as average values, which are representative to a broad range of dairy farms in New Zealand.

A primary use of the experimentation phase of simulation was to determine the effect of decision variables, whereas sensitivity analysis was used mainly for testing the sensitivity of the model to biological parameters such as culling rate or replacement rate. A standard sensitivity analysis technique is to vary the value of a numerical parameter through several levels, leaving all others at standard or base values. An alternative approach known as 'scenario analysis', is to change a range of parameter combinations. In this research, both options were explored, specifying values in advance, normally with equal-size intervals between the levels and recording the results. This allowed comparisons between outputs from the revised model with those from the original model.

Chapter 4

Scenarios, strategies and outcomes

4.1 Introduction

The purpose of this chapter is to present the four herd-conversion scenarios. First, an overview is provided of the baseline scenario of non-testing, followed by a brief description of three alternatives that involve genetic testing of the herd at different levels. Second, a range of alternative conversion strategies that might have an impact on the rate of herd conversion are discussed. The last part of the chapter refers to the presence of A2 beta-casein in the milk, and the impact of a conversion process on herd genetic gain.

4.2 Scenarios

The four scenarios explored in the simulation phase are: (1) non-testing of cows and calves; (2) genetic testing of cows; (3) genetic testing of calves; and (4) genetic testing of both cows and calves.

In order to better represent the A1:A2 allele prevalence in the national herd, comparisons are made using three baseline compositions, termed here as Herds A, B, and C. The unique difference between these baseline compositions is the A1:A2 allele ratio. Herd A has an allele ratio of 1:1, while Herds B and C have a ratio of 2:1 and 1:2 respectively. In all scenarios, results reported here are mainly expressed as the proportion of A2A2 cows after 'x' years.

The initial age structure is identical in the three herds, and reflects survival rates reported in national statistics (Dairy NZ, 2012). For the season 2011-212, survival rates fluctuated from 86% from two to three year-old heifers, down to 67% for nine to ten year-old cows.

Table 4-1: Initial age structure of Herds A, B, and C

Age (years)	2	3	4	5	6	7	8	9	10
Percent of the herd (%)	21	18	15	13	11	9	6	4	3

4.2.1 Non-testing of cows and calves

The baseline scenario occurs when farmers use only A2 semen from A2A2 bulls. As the A1/A2 status of the herd is unknown it is impossible to identify, at an individual animal level, which animal belongs to which genotype (A1A1, A1A2 or A2A2). The A2A2 calves born will be the progeny of the A2A2 cows, plus half of the progeny of the A1A2 cows. Similarly, the number of A1A2 calves born will be half of the progeny of A1A2 cows and all of the progeny from A1A1 cows. Notably, there will be no more A1A1 calves born.

In this scenario, the selection rate of calves will be the same in both groups, A1A2 and A2A2, but absolute numbers might be different. With regard to cows, by not knowing the A1/A2 status there is a high risk of accidental culling A2A2 cows. The consequence of using A2 semen without genetic testing is that the herd will move to A2, but at a lower rate than by using alternative strategies.

4.2.2 Genetic testing of cows

The second scenario occurs when a farmer uses A2 semen in combination with genetic testing of cows. The importance of knowing the A1/A2 status of the cows is to guide culling decisions. Thus, if cows have been tested, culling of cows starts with the A1A1 sub-herd, following by the A1A2, and A2A2 respectively. The impact of genetic testing of cows is bigger in herds with a low involuntary culling rate, due to the greater chances for selective culling. In contrast, if the involuntary culling rate is high there is a limited margin for selective culling, unless it is accompanied by high replacement rates.

4.2.3 Genetic testing of calves

The third scenario occurs when a farmer uses A2 semen in combination with genetic testing of calves. The main benefit of this strategy is to improve the efficiency of calf selection. When the A1/A2 status of calves is known, the selection criteria will be to keep as many A2A2 calves as possible, taking the residual from the A1A2 group. The A1/A2 status of calves out of A1A2 cows cannot be determined by the genotype of these dams. In practice, genetic testing of calves also solves the problem of parentage errors which is very common under New Zealand conditions where calving is seasonal and hence concentrated, and birth occurs under field rather than confined conditions.

4.2.4 Genetic testing of both cows and calves

The fourth scenario occurs when A2 semen is used in combination with genetic testing of both cows and calves. This decision combines the benefits in the previous two scenarios, i.e. high efficiency in the process of calf selection and voluntary culling of cows.

4.3 Strategies

Using the model, a series of experiments are conducted to explore the impact of alternative strategies. These alternative breeding strategies are: (1) the impact of replacement rate (RR) and/or involuntary culling rate (IC); (2) the impact of artificially mating yearlings with A2 semen; and (3) the impact of using A2 sexed semen.

4.3.1 Variations in the replacement rate and involuntary culling rate

The speed of conversion to A2 is a function of the generation interval. A higher replacement rate reduces the generation interval, but modifies the age structure and the herd becomes younger. In addition, high culling rates demand a large number of replacements to maintain herd numbers, which also contributes to reducing the generation interval. In the context of herd conversions, one challenge is to find the optimal replacement rate that maximizes the rate of progress to A2 without causing a major impact on herd performance. A key issue here is the number of A2A2 calves available to select from.

The feasible replacement rates are initially limited by the decision as to whether or not to artificially mate yearlings with A2 semen. This is a key decision under New Zealand conditions, whereby calves are often raised through agistment on farms that are distant from the milking platform and the location of the herd owner, and where handling facilities may be limited. Hence, most New Zealand dairy farmers do not use artificial insemination of yearlings with premium semen, and do not select herd replacements from their first-calving progeny.

Without selecting calves from first-calving heifers, the replacement rate for feasible scenarios fluctuated between 22% and 27%. In contrast, by selecting calves from first-calving heifers, the replacement rates explored fluctuated between 25% and 35%. This is valid for all scenarios, regardless of the initial baseline composition of herds. Additionally, when sexed semen is used, the

simulation phase considered a maximum replacement rate of 47%. The baseline involuntary culling rate was 15% and comparisons were made between a low (10%) and a high (20%) rate.

4.3.2 Artificial insemination (AI) of yearlings with A2 semen

The implications of artificially mating yearlings with A2 semen are varied but interrelated. First, additional replacements would be available, allowing adoption of a higher replacement rate. Second, reducing the generation interval increases the rate of progress to A2. Third, there is increased potential for herd genetic gain as a consequence of the reduced generation interval. In practice, many yearling heifers are naturally mated and the offspring are not kept as replacements. In a herd without herd replacements available from first-calving heifers the opportunity to select A2A2 replacement calves can be constrained, particularly in the early years of herd conversion. For all the simulated scenarios, both situations are compared in order to evaluate the impact on the rate of progress to pure A2.

4.3.3 A2 sex-selected semen

Using sex-selected semen would greatly increase the number of A2A2 calves available to select replacement heifers. In doing this, dairy farmers can speed up conversions and/or have more space for internal expansion. The current (2013) situation is that female-sexed semen can achieve 90% of female calves born (CRV Ambreed, 2013b). However, there are some constraints. First, A2 sex-selected semen can be expensive (cash cost). Second, the pregnancy rate using sex-selected semen is lower than non-sexed semen. Finally, it is important to note that sex-selected semen is a product available from only a few proven sires (alternative cost). For investigations reported here, it is assumed that the proportion of female calves born from non-sexed semen is 50% and from sexed semen is 90%.

4.4 Outcomes

The rate of herd conversion, reported here as the proportion of A2A2 cows after 'x' years, has been approached in each scenario using different decision variables (e.g. genetic testing of cows, the use of sex-selected semen). In addition, the percentage of the A2 beta-casein in the milk and how decisions might impact on the rate of genetic progress (measured by BW) are investigated in this research.

4.4.1 A2 beta-casein in the milk

The proportion of the A2 beta-casein allele in the herd and the proportion of A2 beta-casein in the milk are not necessarily the same. In the milk, it is a function of the percentage of A2A2 cows plus half of the percentage of A1A2 cows, mediated by milk production by age group in each sub-herd.

In the herd the allele frequency is simply equal to the percentage of A2A2 cows plus half of the percentage of A1A2 cows. Accordingly, given that the A2 allele frequency during the herd conversion process will typically be higher in young cows than old cows, it is to be expected that the percentage of A2 beta-casein in the milk will lag the percentage of the A2 beta-casein allele in the herd.

4.4.2 Herd genetic gain

Farmers moving to A2 may experience a reduced rate of genetic gain, as a consequence of being unable to use semen from some otherwise elite bulls that are either A1A1 or A1A2. However, even though the BW of A2 bull teams might be lower than using a combination of bulls from different genotypes, it will be much higher than the average genetic merit in the female herd. Hence, the potential genetic loss relates not to a decline in the absolute level of genetic merit, but to the expected rate of gain. That is, the herd will still improve its average genetic merit, but at a slower rate.

Chapter 5

Findings

5.1 Introduction

This chapter presents the results of the simulations. According to the structure outlined in Chapter 4, the scenarios are analysed independently. Within each scenario, the three herds (A, B, and C) have been analysed under a set of alternative strategies. This is followed by an analysis of the presence of the A2 beta-casein in the milk, and the impact on herd genetic gain. The final part of the chapter presents a comparison between different scenarios using a set of parameters and decision variables.

For investigations reported here, the main outcome is the proportion of A2A2 cows after ten years, with values reported as percentages. The relationship between the assumed baseline composition of herds and the assumed allele frequency is consistent with Mendelian principles of gene distribution. Accordingly, in Herd A, with an A1:A2 allele ratio of 1:1, 25% of the cows are assumed to be A1A1, 50% A1A2, and 25% A2A2. In Herd B, with an A1:A2 allele ratio of 2:1, 45% of the cows are assumed to be A1A1, 45% A1A2, and 10% A2A2. In Herd C, with an A1:A2 allele ratio of 1:2, 10% of the cows are assumed to be A1A1, 45% A1A2, and 45% A2A2.

5.2 The non-testing scenario

By not knowing the A1/A2 status of the herd, some A2A2 cows and/or calves will be accidentally culled, and the process of selection and culling will become less effective. As a consequence, it is expected that parameters such as replacement rate or decision variables such as artificial insemination of yearlings with A2 semen will have a small impact over the rate of progress to A2.

5.2.1 The impact of replacement rate without genetic testing of animals

Variations in the replacement rate cause little impact on the speed of conversion (Figure 5.1). Regardless of the initial A1:A2 ratio, the annual rate of progress to A2 is about 5% for Herd A and Herd B but about 4% for Herd C. In general, higher replacement rates (e.g. 27%) will speed up the conversion process relative to lower replacement rates (e.g. 22%) but the impact is small.

For instance, the percentage of A2A2 cows in Herd A increases from 25% to 63% after 10 years using a replacement rate of 22% and increases to 70% using a replacement rate of 27%.

In this non-testing situation, it is impossible to convert to a pure A2 herd. This is because, although not fully evident from Figure 5.1, the relationship is curvilinear. After the first cow generation of breeding, the percentage of A1A2 cows remaining in the herd will halve with each further cow generation but will never reach zero.

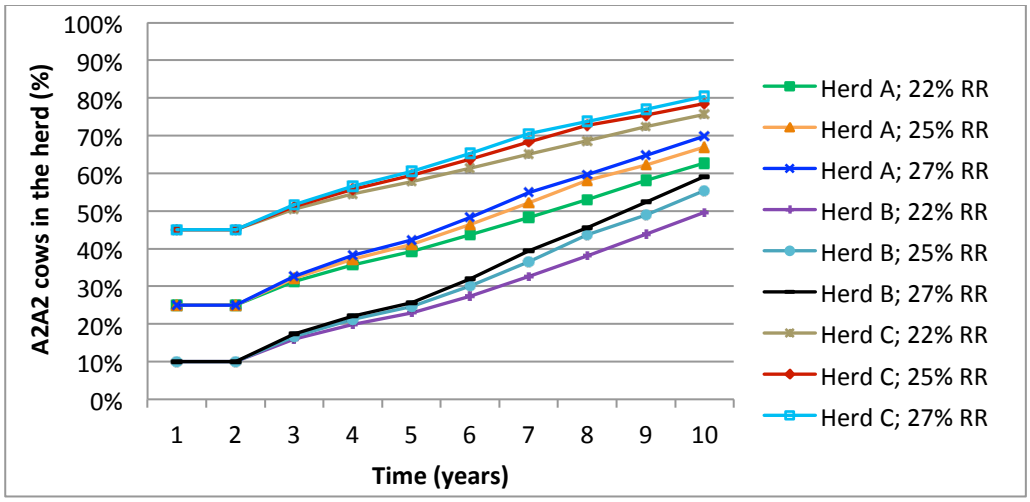

Figure 5-1: Proportion of A2A2 cows over a ten year period in three herds with different initial A2A2 proportions (Herd A = 25%; Herd B = 10%; Herd C = 45%) in a non-testing scenario using three (22%, 25% and 27%) replacement rates (RR), no artificial insemination of yearlings and a 15% involuntary culling rate.

5.2.2 The impact of artificially mating yearlings to A2 semen without genetic testing of animals

This decision will increase the number of A2A2 calves born allowing high replacement rates. In this context, there will be more A2A2 calves to select from, which will affect the rate of herd conversion. The increase in the final proportion of A2A2 cows is caused by the higher A2 allele prevalence in calves born from dams mated as yearlings, than in the older cows.

There is a positive correlation between high replacement rates and a high proportion of A2A2 cows after ten years (Table 5.1). However, in this non-testing situation, artificial insemination of yearlings with A2 semen causes little impact and is not enough to achieve a pure A2 herd.

Compared to herds without artificial insemination of yearlings with A2 semen, using a 25% replacement rate and a 15% involuntary culling rate, the proportion of A2A2 cows after ten years will be higher by 4%, 6% and 3% in herds A, B, and C respectively.

Table 5-1: Proportion of A2A2 cows after ten years in three herds with different initial A2A2 proportions (Herd A = 25%; Herd B = 10%; Herd C = 45%) in a non-testing scenario using three (25%, 30% and 35%) replacement rates, artificial insemination of yearlings with A2 semen and a 15% involuntary culling rate

Herd	Replacement rate (%)		
	25%	**30%**	**35%**
A	71%	78%	82%
B	61%	70%	76%
C	81%	85%	88%

5.2.3 The impact of involuntary culling rate without genetic testing of animals

The combination of a low involuntary culling rate with artificial insemination of yearlings with A2 semen maximises the proportion of A2A2 cows after ten years (Table 5.2). In Herd A, this represents an increment in the proportion of A2A2 cows of about 7%, from 67% to 74%. For herds B and C, the increment represents about 9% and 4% respectively. Although there is an increase in the proportion of A2A2 cows, none of the herds could achieve a pure A2 status within ten years.

In this non-testing scenario, variations in the involuntary culling rate have little impact on the proportion of A2A2 cows after ten years. For example, for Herd A, using 10% instead of a 15% involuntary culling rate, the proportion of A2A2 cows will increase by 3% from 67% to 70%. In contrast, if the involuntary culling rate increases to 20%, the final proportion of A2A2 cows after ten years will drop by 3%. For herds B and C the impact is of similar magnitude (Table 5.2).

Table 5-2: Proportion of A2A2 cows after ten years in three herds with different initial A2A2 proportions (Herd A = 25%; Herd B = 10%; Herd C = 45%) in a non-testing scenario using three (10%, 15% and 20%) involuntary culling rates, optional artificial insemination (AI) of yearlings with A2 semen and a 25% replacement rate

Herd	AI of yearlings with A2 semen	Involuntary culling rate (%)		
		10%	15%	20%
A	No	70%	67%	64%
	Yes	74%	71%	68%
B	No	59%	55%	51%
	Yes	64%	61%	57%
C	No	80%	79%	76%
	Yes	83%	81%	79%

5.2.4 The impact of using A2 sexed semen without genetic testing of animals

In results reported here, using replacement rates ranging from 22% to 35% and involuntary culling rates ranging from 10% to 20%, in combination with artificial insemination of yearlings, the use of A2 sexed semen has no impact on the rate of progress to A2.

A remarkable feature is that using sexed semen allows an increase in the maximum replacement rate to a very high level, about 70%. At such high rates, the speed of herd conversion increases, although a pure herd will still never be achieved in the absence of testing.

In the practically difficult scenario of replacing 50% of the herd each year, with an involuntary culling rate of 15% and yearlings artificially mated with A2 semen, the proportion of A2A2 cows after ten years will be 88%, 84% and 93% for herds A, B and C respectively. In this context, increasing the replacement rate to 70%, the proportion of A2A2 cows after ten years will be 92%, 87% and 95% in herds A, B and C respectively.

5.3 Progress based on genetic testing of cows

Genetic testing of cows maximises culling efficiency. In the absence of testing of calves, the efficacy is mainly determined by the voluntary culling rate rather than the herd replacement rate (Table 5.4). The principle here is; the lower the involuntary culling rates, then the higher the proportion of A2A2 cows after ten years, as there are more options for selective culling. In all situations, knowing the A1/A2 status of cows causes changes on herd profile starting from year two.

5.3.1 The impact of replacement rate based on genetic testing of cows

In all herds, regardless of the initial A2A2 proportion, and with an annual replacement rate of 22%, the annual rate of progress is about 5% (Figure 5.2). Although testing of cows allows selective culling of A1A1 and A1A2 cows, none of the herds could achieve a pure A2 status within ten years using a 25% replacement rate, and an involuntary culling of 15%. The proportion of A2A2 cows after ten years will be 68%, 53% and 83% in herds A, B, and C respectively.

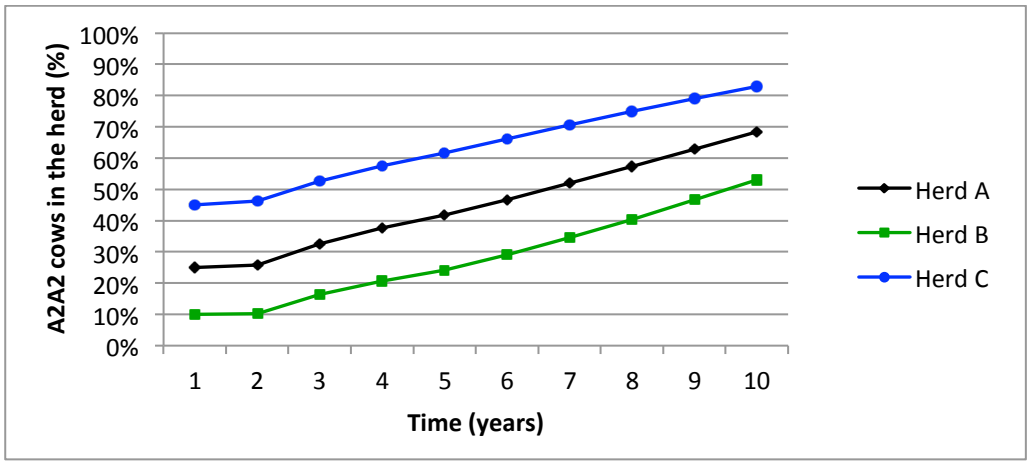

Figure 5-2: Proportion of A2A2 cows over a ten year period in three herds with different initial A2A2 proportions (Herd A = 25%; Herd B = 10%; Herd C = 45%) in the scenario of genetic testing of cows using 22% replacement rate, no artificial insemination of yearlings and a 15% involuntary culling rate

Replacing the herd at higher levels increases the rate of herd conversion, maximising the proportion of A2A2 cows after ten years (Figure 5.3). The annual rate of progress is 6%, 7% and 9% using replacement rates of 22%, 25% and 27% respectively. Although a moderate increase in the replacement rate speeds up the conversion process, it is insufficient to achieve a pure A2 herd within ten years. For example, by using a replacement rate of 27% instead of 22%, the proportion of A2A2 cows after ten years will rise from 68% to 95%.

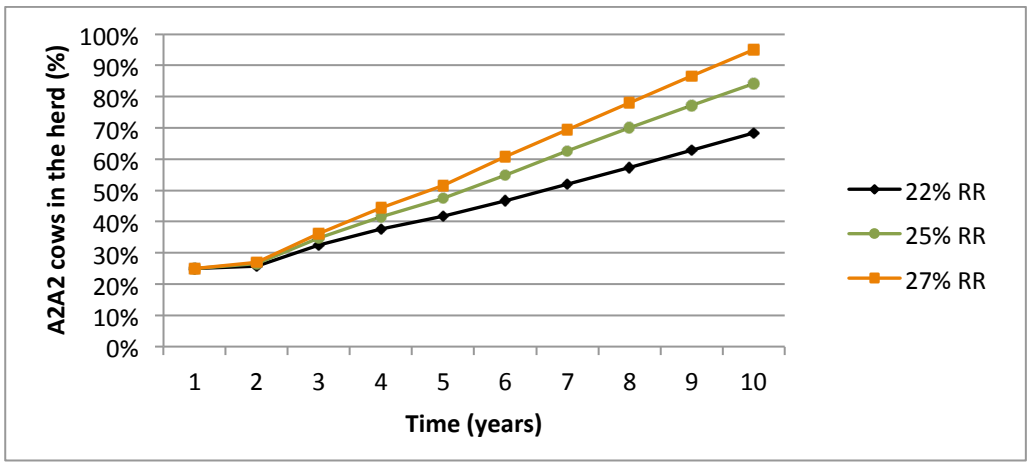

Figure 5-3: Proportion of A2A2 cows over a ten year period in a herd with initial A2A2 proportion of 25% (Herd A) in the scenario of genetic testing of cows using three (22%, 25% and 27%) replacement rates (RR), no artificial insemination of yearlings and a 15% involuntary culling rate

Similarly in both herds B and C, higher replacement rates increase the rate of progress to homozygous A2 (Figure 5.4). In Herd B, an increase in the replacement rate from 22% to 27% causes the proportion of A2A2 cows after ten years to rise from 53% to 76%. In Herd C, this causes the herd to achieve pure A2 status within ten years, using a replacement rate of 27%. The average rate of progress is about 9% until year eight, and then drastically drops to about 1%.

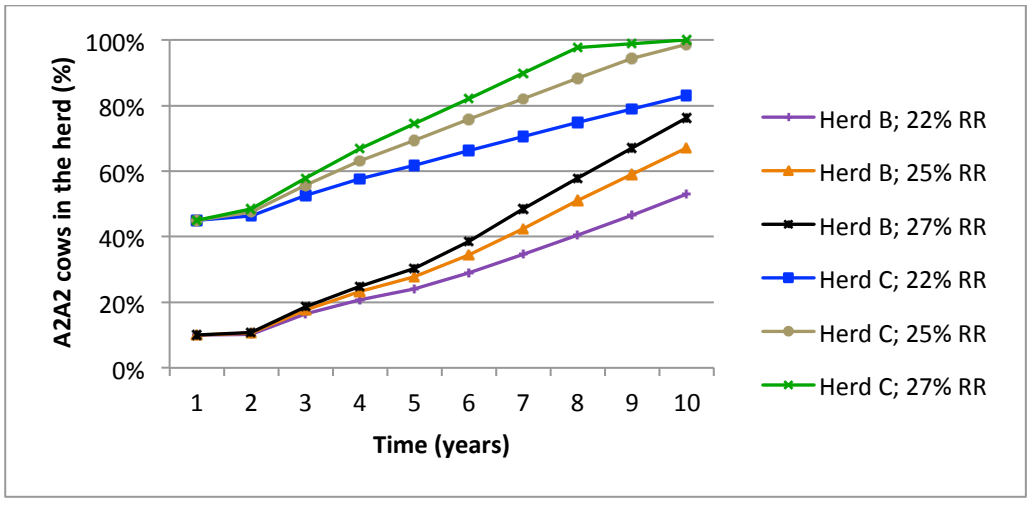

Figure 5-4: Proportion of A2A2 cows over a ten year period in two herds with initial A2A2 proportions (Herd B = 10%; Herd C = 45%) in the scenario of genetic testing of cows using three (22%, 25% and 27%) replacement rates (RR), no artificial insemination of yearlings and a 15% involuntary culling rate

5.3.2 The impact of artificially mating yearlings with A2 semen based on genetic testing of cows

Genetic testing of cows allows early culling of A1A1 and A1A2 cows, increasing the proportion of A2A2 calves born in subsequent years. In addition, artificial insemination of yearlings with A2 semen allows the use of higher replacement rates, thereby increasing the chances that most replacements will be A2A2 calves.

In all herds, the proportion of A2A2 cows increases as the replacement rate increases (Table 5.3). However, comparing the same replacement rate (e.g. 25%) with a herd without artificial insemination of yearlings, the increase is small. For herds A and B this represents about 3% and 5% more A2A2 cows respectively, while there is no variation for Herd C. Using high replacement rates (e.g. 30% and 35%), there is a remarkable increase in all herds but with small differences between using 30% or 35% replacement rates. Herds A and C will be pure A2 after ten years using a replacement rate of 35% and 30% respectively. Notably, regardless of the initial A2 allele frequency, the gap between the herds is considerably reduced at high replacement rates (Table 5.3).

Table 5-3: Proportion of A2A2 cows after ten years in three herds with different initial A2A2 proportions (Herd A = 25%; Herd B = 10%; Herd C = 45%) in the scenario of genetic testing of cows using three (25%, 30% and 35%) replacement rates, artificial insemination of yearlings with A2 semen and a 15% involuntary culling rate

Herd	Replacement rate (%)		
	25%	**30%**	**35%**
A	87%	99%	100%
B	71%	95%	98%
C	99%	100%	100%

5.3.3 The impact of involuntary culling rate based on genetic testing of cows

More important than whether yearlings are artificially mated with A2 semen is variations in the involuntary culling rate, as this has a major impact on the final proportion of A2A2 cows (Table 5.4). In herds A and B, with an involuntary culling rate of 10% instead of 15%, the proportion of A2A2 cows after ten years increases by about 15%. Similarly, the impact caused by a low involuntary culling rate in Herd C represents the difference between completing a herd conversion within ten years or not. These results suggest that the selective culling of cows is important and that it has it greatest effectiveness when involuntary culling is low and voluntary culling is high.

Table 5-4: Proportion of A2A2 cows after ten years in three herds with different initial A2A2 proportions (Herd A = 25%; Herd B = 10%; Herd C = 45%) in the scenario of genetic testing of cows using three (10%, 15% and 20%) involuntary culling rates, optional artificial insemination (AI) of yearlings with A2 semen and a 25% replacement rate

Herd	AI of yearlings with A2 semen	Involuntary culling rate (%)		
		10%	15%	20%
A	No	98%	84%	66%
	Yes	98%	87%	69%
B	No	83%	67%	52%
	Yes	86%	71%	58%
C	No	100%	99%	79%
	Yes	100%	99%	82%

5.3.4 The impact of using A2 sexed semen combined with genetic testing of cows but not genetically testing calves

The use of A2 sexed semen in combination with genetic testing of cows and artificial insemination of yearlings, together with replacement rates ranging from 22% to 35% and involuntary culling rates ranging from 10% to 20%, has no impact on the rate of herd conversion.

By using A2 sexed semen, it is theoretically possible to replace 70% of the herd each year. In the hypothetical scenario of using a 50% replacement rate, the final proportion of A2A2 cows after ten years will not vary. Herds A and C will be pure after ten years, while 98% of the cows will be A2A2 in Herd B. These results are almost the same when using a 35% replacement rate, 15% involuntary culling rate, artificial insemination of yearlings, and with non-sexed A2 semen.

5.4 Progress based on genetic testing of calves

Genetic testing of calves maximises calf selection for the A2 allele. Although testing of calves is a powerful decision option to increase the rate of herd conversion, the benefits of this strategy in combination with high replacement rates are only achieved if there are enough A2A2 calves available to select from.

5.4.1 The impact of replacement rate based on genetic testing of calves

Genetic testing of calves allows a high rate of herd conversion. The percentage of A2A2 cows, with an annual replacement rate of 22% increases at about 8% per annum for herds A and B, and 7% for Herd C. After ten years, the proportion of A2A2 cows has increased from 25% to 91% in Herd A, from 10% to 74% in Herd B, and from 45% to 99% in Herd C (Figure 5.5).

Although none of the herds achieve a pure status, the final proportion of A2A2 cows after ten years is much higher compared with the results obtained in the non-testing situation or compared with the results obtained when cows have been tested (Figure 5.1; 5.2).

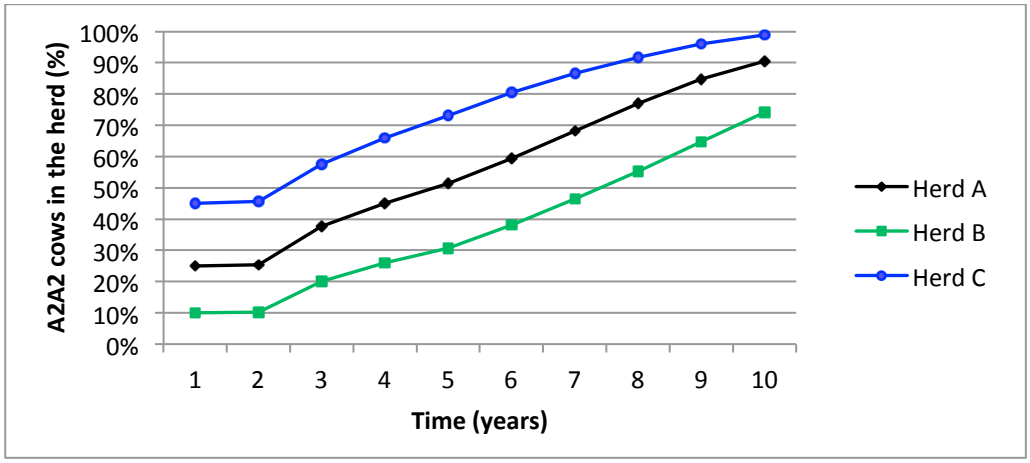

Figure 5-5: Proportion of A2A2 cows over a ten year period in three herds with different initial A2A2 proportions (Herd A = 25%; Herd B = 10%; Herd C = 45%) in the scenario of genetic testing of calves using a 22% replacement rate, no artificial insemination of yearlings and a 15% involuntary culling rate

Although genetic testing of calves has a positive impact on the final proportion of A2A2 cows, when combined with high replacement rates there can be a counter-productive effect in the rate of herd conversion unless A2A2 calves are available from artificial insemination of yearlings. This is because high replacement rates force the selection of some A1A2 calves, which reduces the rate of progress in the long run (Figure 5.6).

Assuming a 22% replacement rate, the percentage of A2A2 cows increases at about 8% per annum. However, with 25% and 27% replacement rates, the annual rate of progress is reduced to 7% and 6% respectively. At this speed of conversion the percentage of A2A2 cows after ten years will be 83% and 75% respectively.

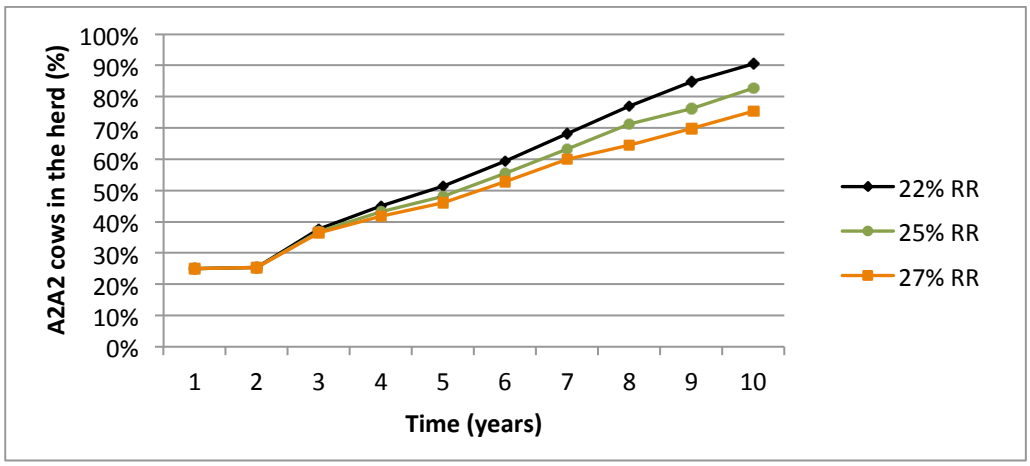

Figure 5-6: Proportion of A2A2 cows over a ten year period in a herd with an initial A2A2 proportion of 25% (Herd A) in the scenario of genetic testing of calves using three (22%, 25% and 27%) replacement rates (RR), no artificial insemination of yearlings and a 15% involuntary culling rate

The negative impact over the rate of herd conversion caused by increasing the replacement rate also affects herds B and C (Figure 5.7). For Herd A, the annual rate of herd conversion drops from 8% to 7% after increasing the replacement rate from 22% to 27%. As a consequence, in ten years time, the proportion of A2A2 cows will be 63% instead of 74%. In Herd C there is a similar trend but the magnitude of the impact is greater (Figure 5.7). A high replacement rate (27%) causes a drop in the rate of herd conversion from 7% to 5%. Hence, using a 27% replacement rate the proportion of A2A2 cows after ten years will be about 12% lower than it could otherwise be using a 22% replacement rate. This represents 87% A2A2 cows instead of 99%.

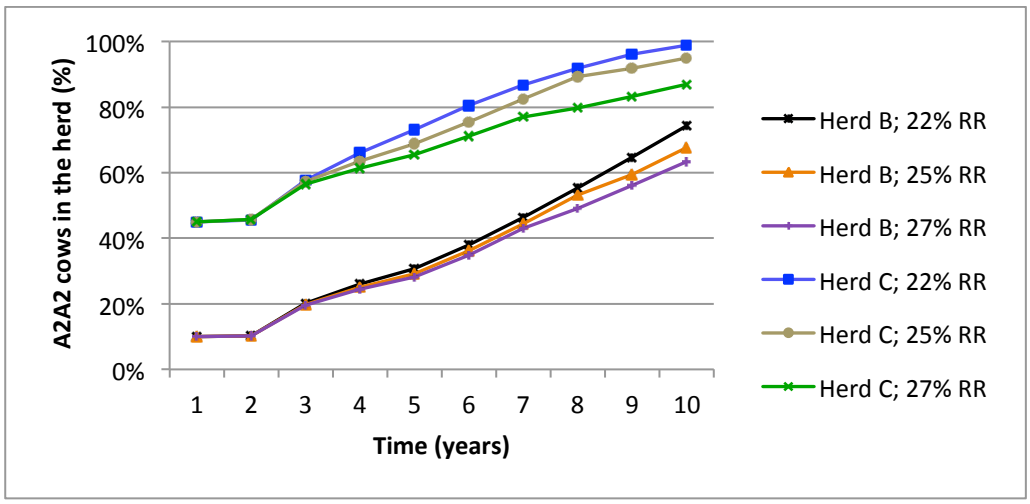

Figure 5-7: Proportion of A2A2 cows over a ten year period in two herds with different initial A2A2 proportions (Herd B = 10%; Herd C = 45%) in the scenario of genetic testing of calves using three (22%, 25% and 27%) replacement rates (RR), no artificial insemination of yearlings and a 15% involuntary culling rate

5.4.2 The impact of artificially mating yearlings with A2 semen based on genetic testing of calves

The combination of genetic testing of calves, artificial insemination of yearlings with A2 semen, and high replacement rates has a positive impact on the rate of herd conversion (Table 5.5). In the presence of artificial insemination of yearlings to A2 semen the herd can be replaced at higher rates, which in combination with the testing of calves maximises the final proportion of A2A2 cows. Herds A and C will be pure after ten and nine years respectively, using a replacement rate of 25%. At the same rate, in Herd B, the proportion of A2A2 cows after ten years will increase from 68% to 95% if yearlings are inseminated with A2 semen.

Table 5-5: Proportion of A2A2 cows after ten years in three herds with different initial A2A2 proportions (Herd A = 25%; Herd B = 10%; Herd C = 45%) in the scenario of genetic testing of calves using three (25%, 30% and 35%) replacement rates, artificial insemination of yearlings with A2 semen and a 15% involuntary culling rate

Herd	Replacement rate (%)		
	25%	30%	35%
A	100%	100%	98%
B	95%	96%	93%
C	100%	100%	100%

5.4.3 The impact of involuntary culling rate based on testing of calves

Regardless of the initial A2A2 proportion in the herd, and in the absence of cow testing, whether or not yearlings are artificially inseminated with A2 semen has a greater impact than variations in the involuntary culling rate (Table 5.6). In the context of testing of calves but without the testing of cows, the inefficiency of the culling process (risk of accidental culling) is minimised by the decision to artificially mate yearlings with A2 semen due to the higher prevalence of the A2 allele in younger cows.

Table 5-6: Proportion of A2A2 cows after ten years in three herds with different initial A2A2 proportions (Herd A = 25%; Herd B = 10%; Herd C = 45%) in the scenario of testing of calves using three (10%, 15% and 20%) involuntary culling rates, optional artificial insemination (AI) of yearlings with A2 semen and 25% replacement rate

Herd	AI of yearlings with A2 semen	Involuntary culling rate (%)		
		10%	15%	20%
A	No	87%	83%	78%
	Yes	100%	100%	97%
B	No	73%	68%	62%
	Yes	98%	95%	91%
C	No	97%	95%	93%
	Yes	100%	100%	100%

5.4.4 The impact of using A2 sexed semen based on testing of calves

In the scenario of genetic testing of calves, the combination of using A2 sexed semen with the artificial insemination of yearlings represents a powerful set of decision options that can be used to speed up a herd conversion process. The impact of using sexed A2 semen is greater using high replacement rates, but moderate using low rates. In results reported here, it is assumed that yearlings are artificially inseminated with A2 semen, and the involuntary culling rate is 15%.

Depending on the initial proportion of A2A2 cows and the replacement rate, it is possible to achieve a pure A2 herd in less than ten years, although at the cost of having a younger herd (Table 5.7). For example, herds A and B will be pure A2 after six and eight years respectively, using a 35% replacement rate, with a herd that is predominantly of two, three and four-year-old cows. Similarly, the fastest option for Herd C is five years using a 40% replacement rate, with a herd that is made up entirely of two and three-year-old cows.

Table 5-7: Time (years) required to achieve a pure A2 herd starting with different initial A2A2 proportions (Herd A = 25%; Herd B = 10%; Herd C = 45%) in the scenario of genetic testing of calves, artificial insemination of yearlings, using A2 sexed semen and four (25%, 30%, 35% and 40%) replacement rates.

Herd	Replacement rate (%)			
	25%	30%	35%	40%
A	8	7	6	7
B	9	9	8	8
C	8	7	6	5

5.5 Progress based on genetic testing of the herd, including both cows and calves

Genetic testing of both cows and calves combines the benefits of the highly efficient processes of both cow culling and calf selection. As a result, the initial A2A2 proportion in the milking herd starts changing in year two.

5.5.1 The impact of replacement rate based on genetic testing of the herd, including cows and calves

Variations in the replacement rate cause little impact on the rate of herd conversion. However, regardless of the initial A2A2 proportion, the annual rate of progress increases to about 9%. Although in some situations the conversion process could not be completed within ten years, the A2A2 proportion increases considerably (Figure 5.8). For instance, Herd A will be pure in year 10 using a replacement rate of 25%, while at 22% or 27% the A2A2 proportion will be 95% and 99% respectively. In Herd B, using a 25% replacement rate increases the A2A2 proportion from 10% to 82% after ten years. Herd C will be pure A2 within eight years using a replacement rate of 25%, or within nine years using 22% and 27% replacement rates.

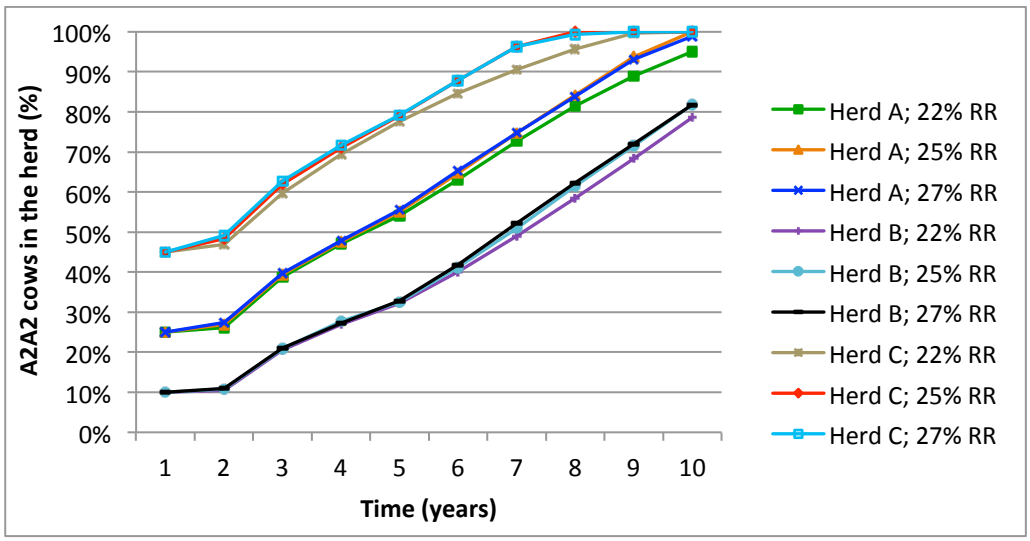

Figure 5-8: Proportion of A2A2 cows over a ten year period in three herds with different initial A2A2 proportions (Herd A = 25%; Herd B = 10%; Herd C = 45%) in the scenario of genetic testing of cows and calves using three (22%, 25% and 27%) replacement rates (RR), no artificial insemination of yearlings and a 15% involuntary culling rate

5.5.2 The impact of artificially mating yearlings with A2 semen based on genetic testing of the herd, including cows and calves

The combination of genetic testing of cows and calves, artificial insemination of yearlings with A2 semen and high replacement rates speeds the rate of herd conversion, but the magnitude of the effect is influenced by the replacement rate (Table 5.8). For instance, artificial insemination of yearlings using a 25% replacement rate, herds A, B and C will be pure in eight, ten and seven years respectively. That is, a conversion process can be completed two years earlier for Herd A, and one year earlier for Herd C, compared to herds without artificial insemination of yearlings with A2 semen. For Herd B, it is possible to achieve purity in year ten; otherwise the herd will be only 82% of A2A2 cows at that time. Using a 30% replacement rate can further speed up the conversion process to six, nine, and seven years for herds A, B, and C respectively.

Table 5-8: Time (years) required to achieve a pure A2 herd starting with different initial A2A2 proportions (Herd A = 25%; Herd B = 10%; Herd C = 45%) in the scenario of genetic testing of cows and calves using three (25%, 30% and 35%) replacement rates, artificial insemination of yearlings with A2 semen and a 15% involuntary culling rate

Herd	Replacement rate (%)		
	25%	30%	35%
A	8	7	7
B	10	9	9
C	7	6	6

5.5.3 The impact of involuntary culling rate based on genetic testing of the herd, including cows and calves

Low involuntary culling rates (10%) in combination with artificial insemination of yearlings with A2 semen impact positively on the rate of herd conversion. In contrast, a high involuntary culling rate (20%) reduces the speed of conversion. In all herds, artificial insemination of yearlings with A2 semen can contribute to minimising this drop (Table 5.9). Regardless of whether or not yearlings are artificially inseminated with A2 semen, using a 10% involuntary culling rate, herds A, B and C become pure A2 within ten years.

The decision about artificially mating yearlings with A2 semen can further speed up the process. For example, Herd A will be pure A2 after seven years instead of eight if yearlings are inseminated with A2 semen. For Herd B the conversion process will take nine years instead of ten, while for Herd C the process is completed in six years, regardless of whether yearlings are mated to A2 semen. A high involuntary culling rate of 20% compared to a rate of 15% reduces the proportion of A2A2 cows in herds A and B by 19% and 18% respectively, and 9% in Herd C. However, if yearlings are artificially inseminated with A2 semen this effect can be minimised but not completely avoided.

Table 5-9: Proportion of A2A2 cows after ten years in three herds with different initial A2A2 proportions (Herd A = 25%; Herd B = 10%; Herd C = 45%) in the scenario of genetic testing of cows and calves using three (10%, 15% and 20%) involuntary culling rates, optional artificial insemination (AI) of yearlings with A2 semen and a 25% replacement rate

Herd	AI of yearlings with A2 semen	Involuntary culling rate (%)		
		10%	**15%**	**20%**
A	**No**	100%	100%	81%
	Yes	100%	100%	98%
B	**No**	100%	82%	64%
	Yes	100%	100	91%
C	**No**	100%	100%	96%
	Yes	100%	100%	100%

5.5.4 The impact of using A2 sexed semen based on genetic testing of the herd, including both cows and calves

In the context of genetic testing of cows and calves with artificial insemination of yearlings to A2 semen, the use of sex-selected semen is a decision that has great impact. The benefits of using sexed semen are maximised using high replacement rates (Figure 5.9).

It is observed that for herds A and B, using a 35% replacement rate, a pure A2 herd is achieved in five and six years respectively, with a herd that entirely consists of two, three and four-year old cows. For Herd C, the quickest option is four years using a 40% replacement rate, with a herd comprising entirely of two and three-year-old cows. In all situations, higher replacement rates cannot further speed up the process.

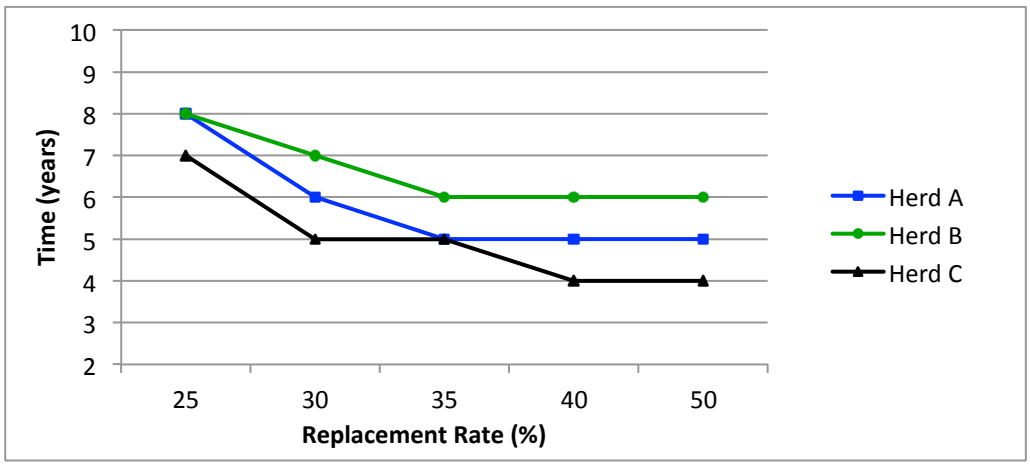

Figure 5-9: Time (years) required to achieve a pure A2 herd starting with different initial A2A2 proportions (Herd A = 25%; Herd B = 10%; Herd C = 45%) in the scenario of genetic testing of cows and calves using three (25%, 30% and 35%) replacement rates, A2 sexed semen, artificial insemination of yearlings and a 15% involuntary culling rate

5.6 A2 beta-casein in the milk

The proportion of A2 beta-casein in the milk is first determined by the proportion of the A2 allele in the herd (i.e. homozygous A2 cows plus half of the heterozygous A1A2 cows). In addition, A2 beta-casein in the milk is influenced by lower production from younger cows, where the incidence of the A1 allele will be lower. Hence the proportion of A2 beta-casein in the milk is different from the proportion of the A2 cows in the herd.

For calculations reported here, the proportion of A2 beta-casein in the milk and the percentage of A2A2 cows over a fifteen year period have been explored, in a non-testing situation (Figure 5.10). It is assumed an initial A2 allele frequency is 50% (Herd A), a 25% replacement rate, a 15% involuntary culling rate, and without the artificial insemination of yearlings with A2 semen. In addition, it is assumed that the two-year-old heifers produce about 23% less milk than older cows (DairyNZ, 2012).

In this context, the proportion of A2 beta-casein in the milk increases over time with a function that is curvilinear and asymptotic. In the early years, the function is close to linear with an annual rate of increase of about 4%, but in the long run exhibiting a declining slope. In the last five years, the rate of increase is reduced to less than 2%. Furthermore, there is no milking-herd impact before year 3 (Figure 5.10).

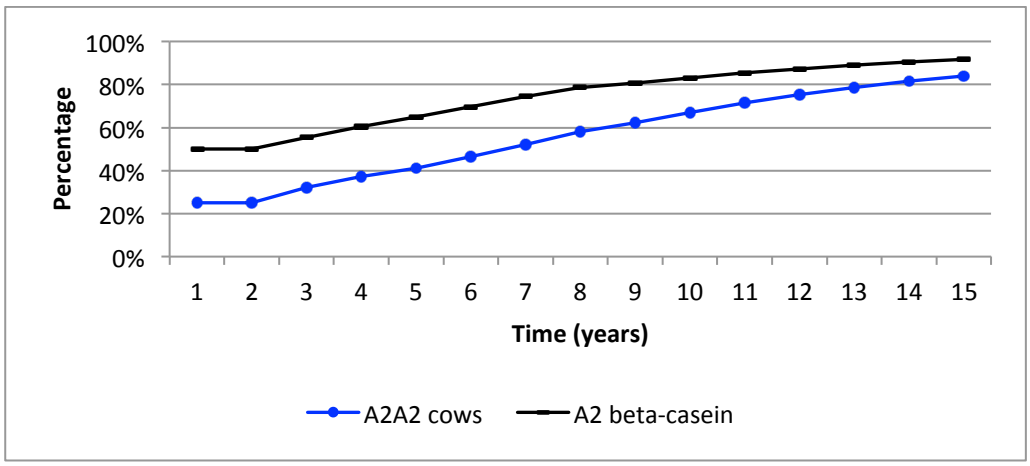

Figure 5-10: Comparison of the proportion of A2 beta-casein in the milk and the proportion of A2A2 cows over a fifteen year period in a herd with an initial A2 allele frequency of 50% (25% A2A2 cows) for a non-testing situation.

In testing situations, the rate of increase is greater, and the time lag before there is any milking-herd impact is reduced to two years. For instance, in the testing of calves using the same parameters as stated above, the annual rate of increase is initially about 7% with an almost linear decline over time until herd purity.

5.7 Herd genetic gain

The rate of genetic gain is a function of the generation interval and the BW of the bulls. In general, regardless of the initial A2A2 proportion in the herd, any decision that reduces the generation interval enhances the rate of herd genetic gain. Consequently, artificial insemination of yearlings and high replacement rates, or a combination of both, has a positive impact on the rate of genetic progress.

5.7.1 The impact of a drop in the average BW of bulls

Given that the decision to use exclusively A2 bulls might cause a decline in the average BW of bull teams, two hypothetical scenarios have been modelled: (1) a drop of 20 units in the initial average BW of bull teams, and (2) a drop of 40 BW units. Although the initial BW of bulls has been lowered, the bull BW is still assumed to increase in subsequent years from this lowered starting point by ten units per year.

For investigations reported here, the initial genetic merit of herds reflects the 2011/12 average dairy herd in New Zealand, with a BW of 77 (DairyNZ, 2012). In regard to the BW of bull teams, an initial BW of 240 is assumed on the basis of the 2012 LIC Premier Sires Team which ranged from 216-260 (LIC, 2013). Based on these values, assuming no loss of initial BW of the bull team, the average rate of herd improvement is assumed to be 15 BW units per annum (Figure 5.11).

Assuming a drop of 20 units in the BW of the bull team, after ten years the average BW of the herd will be 13 units lower than what it could have been. That is, it would take eleven years to get the genetic gain that would otherwise have been obtained in ten years. Similarly, if the initial BW of the bull team drops by 40 units, the average BW of the herd after ten years will be lowered by 27 units, representing the genetic gain of two years (Figure 5.11). In these two hypothetical situations it is observed that the herd BW does not decline, it merely slows down the rate of potential increase. Hence, although the BW of the A2A2 sires has been lowered 20 or 40 units, the BW of cows will continue increasing, but at a lower rate than if a broader range of elite breeding bulls had been available.

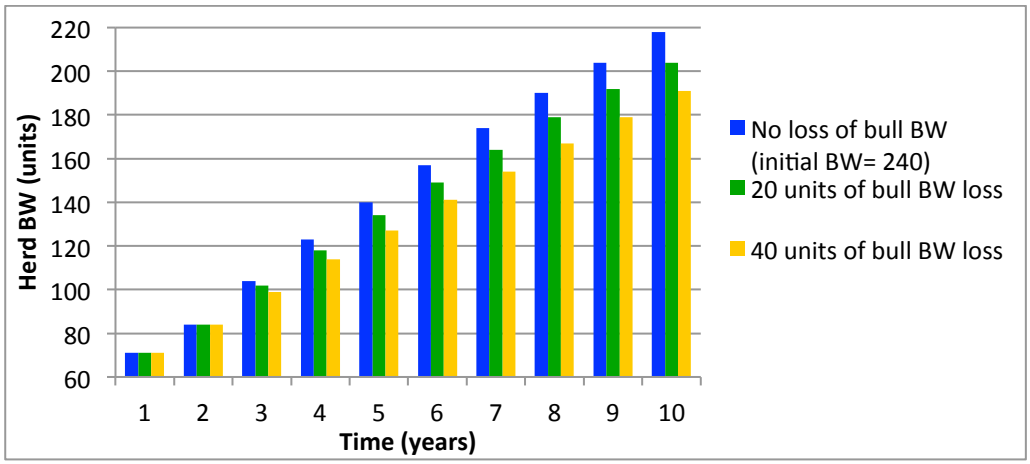

Figure 5-11: The effect on herd genetic gain (BW units) for alternative scenarios of bull BW loss (20 and 40 units) in a non-testing scenario using only A2 semen, no artificial insemination of yearlings and a replacement rate of 25% (15% involuntary culling rate)

Finally, artificial insemination of yearlings with A2 semen is a potential counteracting strategy for BW loss. For instance, the scenario of non-testing, and selecting replacements from first-calving cows reduces the drop in herd BW after ten years by seven units. In testing situations, genetic testing of calves can further reduce herd BW loss by three and two units when there is a decline in the average BW of the bull team of 20 and 40 units respectively, while genetic testing of cows is counter-productive and does not help in reducing the potential drop on herd BW.

5.8 Combining management scenarios and decision strategies

In developing a conversion process it is likely that different farmers will choose different strategies based on their risk profile, their risk perceptions, and their willingness to pursue new business opportunities. To give farmers proactive guidance on how decisions lead to different results, outcomes are presented in two forms. First, the rate of herd conversion (measured as A2A2 cows in the herd) is compared assuming different decision strategies for different scenarios (Figure 5.12). Results indicate that the lowest rate of herd conversion is observed in the non-testing scenario, but a progressive increase occurs when genetic testing includes cows, calves or both. In addition, there are a range of decisions that can further increase the rate of progress, for example, artificial insemination of yearlings to A2 semen and/or high replacement rates.

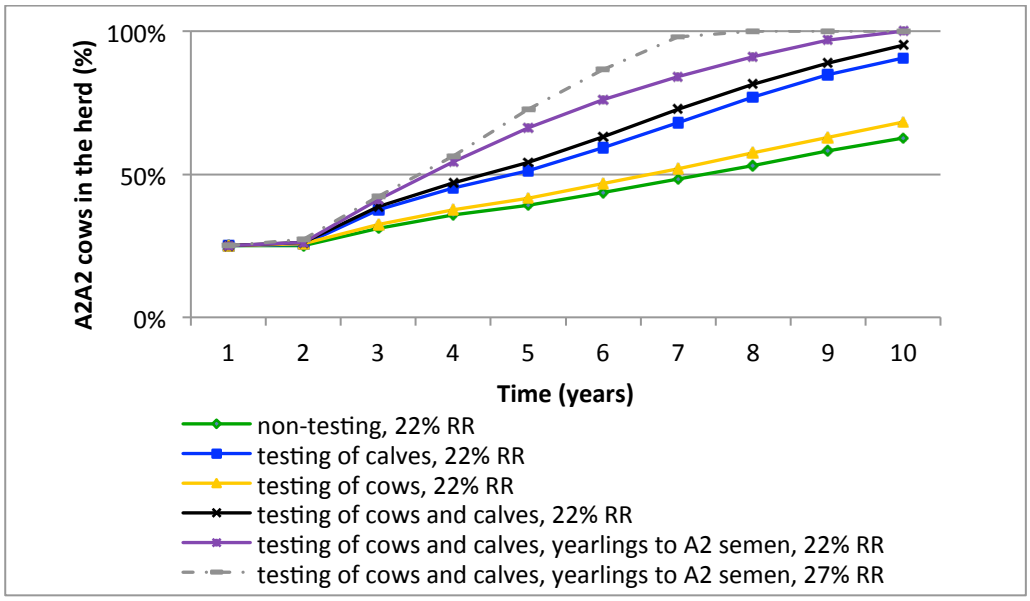

Figure 5-12: Proportion of A2A2 cows over a ten year period in a herd with an initial A2 allele frequency of 50% (25% A2A2 cows) for alternative decision strategies

Second, depending on the initial herd structure and scenarios, a summary is provided of the final proportion of A2A2 cows and the numbers of years required to achieve a pure A2 herd (Table 5.10). In some situations, a conversion process takes more than fifteen years to be completed, although this is not specified. Some key messages are: (1) in a non-testing scenario the process will never be completed; (2) genetic testing of calves is more effective than genetic testing of cows; (3) the fastest option is a combination of genetic testing of calves and cows and high replacement rates, and of using A2 sex-selected semen.

Table 5-10: Proportion of A2A2 cows after ten years and time (years) to achieve a pure A2 herd for alternative management scenarios, and different initial A2A2 herd proportions (Herd A = 25%, Herd B = 10%, Herd C = 45%)

Management scenario			Herd A		Herd B		Herd C	
Testing strategy	Repl. rate (%)	Yearlings mated with A2 semen	A2A2 cows after 10 years (%)	Time to pure A2A2 level (years)	A2A2 cows after 10 years (%)	Time to pure A2A2 level (years)	A2A2 cows after 10 years (%)	Time to pure A2A2 level (years)
Non-testing	22	No	63	>15	50	>15	76	>15
		Yes	66	>15	54	>15	78	>15
	27	No	70	>15	59	>15	80	>15
		Yes	74	>15	65	>15	83	>15
	32	No	nf[1]	nf[1]	nf[1]	nf[1]	nf[1]	nf[1]
		Yes	80	>15	73	>15	87	>15
Testing of cows	22	No	68	>15	53	>15	83	>15
		Yes	71	>15	57	>15	85	>15
	27	No	95	12	76	15	100	10
		Yes	97	12	80	14	100	10
	32	No	nf[1]	nf[1]	nf[1]	nf[1]	nf[1]	nf[1]
		Yes	99	11	97	13	100	10
Testing of calves	22	No	91	15	74	>15	99	12
		Yes	99	12	93	14	100	10
	27	No	75	>15	63	>15	87	>15
		Yes	100	10	96	13	100	8
	32	No	nf[1]	nf[1]	nf[1]	nf[1]	nf[1]	nf[1]
		Yes	100	10	96	12	100	9
Testing of cows and calves	22	No	95	11	79	14	100	10
		Yes	100	10	95	11	100	9
	27	No	99	11	82	13	100	9
		Yes	100	8	100	9	100	6
	32	No	nf[1]	nf[1]	nf[1]	nf[1]	nf[1]	nf[1]
		Yes	100	7	100	8	100	5
Testing of cows and calves, using sexed semen	22	No	100	10	99	11	100	9
		Yes	100	10	100	10	100	9
	27	No	100	7	100	9	100	6
		Yes	100	7	100	8	100	6
	32	No	100	6	100	8	100	5
		Yes	100	6	100	7	100	5
	37	No	100	7	100	9	100	6
		Yes	100	5	100	6	100	4
	42	No	nf[1]	nf[1]	nf[1]	nf[1]	nf[1]	nf[1]
		Yes	100	5	100	6	100	4
	47	No	nf[1]	nf[1]	nf[1]	nf[1]	nf[1]	nf[1]
		Yes	100	5	100	6	100	4

1: non-feasible

Chapter 6

Discussion and conclusions

6.1 Introduction

The purpose of this chapter is to answer the main research question as well as the complementary questions of this thesis. The first part of this chapter provides a decision analysis focused on farmer strategies. The second part of the chapter is an analysis of the A2 beta-casein in milk, and the impact of a conversion process on herd genetic gain. At the end of the chapter a summary of the key findings of this research are outlined.

6.1.1 Farmer strategies

The first decision that needs to be taken before starting a conversion process is whether to use only A2 semen, and whether to undertake genetic testing of cows and/or genetic testing of calves. Use, by farmers, of the baseline scenario based solely on using A2 semen has not been formally documented, but it is likely at the time of writing (2013) to be the most common approach amongst dairy farmers converting to A2 in New Zealand. With this strategy, farmers minimise risk, positioning themselves to quickly conclude the process by adopting a more active approach if market conditions require it.

Farmers using exclusively A2 semen without genetic testing of cows and calves will start moving their herds toward higher A2 status because the A2 allele is much higher in the calves than in the older cows. In the early years, regardless of the initial A1:A2 ratio, the frequency of the A2 allele on these herds will have an increase that is almost linear, at about 5% per annum, but in the long run the rate of herd conversion progressively declines.

As long as there are A1A2 cows in the herd, half of their progeny will be A1A2, and then every generation it is possible to halve the A1 frequency of the allele. This is the reason why, using this approach, a herd will never reach purity. Further, the overall rate of progress will not be affected greatly by different herd replacement decisions, because they are inefficient without genetic testing of animals. Arguably, based on this passive approach, associated herd replacement polices (e.g. higher replacement rates or use of A2 semen for yearlings) should not be altered, given the limited benefits.

Farmers who perceive herd conversion as a business opportunity for profit maximisation, rather than a risk management strategy, might opt for a more active approach that maximises the rate of herd conversion. In this context, a decision needs to be taken in regard to testing of cows, testing of calves, or both. Knowing the A1/A2 status at an individual animal level provides a range of associated farm strategies.

First, farmers owning more than one farm may choose to start with genetic testing of cows. Then they can split the herd, shifting all the A2A2 animals on to one farm, and all the A1A1 and A1A2 to the other. This strategy allows a rapid achievement of pure A2 status, to the extent that by having two herds, the farmer only has to have 50% A2A2 cows on each farm, to allow them to get one pure A2 herd. However, those farmers who have done this and obtained a combined herd that is 80% A2A2 cows, it is possible to complete the conversion process relatively quickly by culling selectively, or buying in A2A2 animals.

Second, farmers owning a single dairy unit may choose to genetically test calves as a first step to rapidly optimising breeding decisions. In any case, the genetic testing of cows and/or calves is not an exclusive option for farmers owning either one or multiple farms. Indeed, looking at an industry level, the combination of A2 semen and genetic testing of animals without being able to buy in A2A2 cows, is the only long-term strategy for converting the national herd to A2.

To achieve a pure A2 herd in the shortest possible time, as well as deciding about the exclusive use of A2 semen and testing strategies, farmers will need to take further decisions to speed up the rate of herd conversion, and the efficacy of selection for the A2 allele. Amongst these decisions, the chosen set of decisions are likely to be; variations in the replacement rate, artificial insemination of yearlings with A2 semen, and the use of A2 sexed semen.

The benefits of high replacement rates vary in different scenarios. In a non-testing scenario, high replacement rates are relatively inefficient due to accidental culling of A2A2 cows or unwanted selection of A1A2 calves. Thus, regardless of the initial A1:A2 ratio, the rate of progress will not vary greatly, and the herd will never become pure A2. In testing situations, high replacement rates are effective when there are enough A2A2 replacements to select from. In situations where the required number of calves exceeds the available number of A2A2 calves in the herd, for example in herds without selection of calves from first-calving heifers, high replacement rates should be avoided because it slows the progress to A2. Furthermore, in herds with a high culling rate for reasons other than production, such as infertility, disease or lameness, high replacement rates are ineffective as there is less opportunity for voluntary culling of A1A1 or A1A2 cows.

The majority of farmers in New Zealand do not select any calves from first-calving heifers. In practice, yearlings are grazed off-farm and naturally mated. As reported in national statistics, the number of yearlings mated to AI in the 2011/12 season was 176,965 (DairyNZ, 2012) which is only 18% of the potential 982,184 yearlings mated in the corresponding season (G. Hansson, personal communication, March 19th, 2013) However, there is an advantage in artificially mating yearlings with A2 semen which is that the decision will give farmers more A2A2 replacements in following years. Indeed, artificial mating of yearlings only has to be done for a few years, until there are enough pure A2A2 calves from the older cows to provide the required number of replacements. Arguably, if farmers are not going to select calves from first-calving heifers, there is no reason for artificially inseminating the yearlings with A2 semen.

Farmers who are more serious about herd conversion may further decide to use A2 sexed semen. Mating the herd with A2 sexed semen will result in a large increase in the proportion of female calves born. The full benefits of this decision are only achieved in combination with genetic testing of cows and calves, artificial insemination of yearlings, and high replacement rates. In this context, the use of A2 sexed semen leads to rapid achievement of herd purity. In a non-testing situation, the use of A2 sexed semen will not provide large advantages in regard to the speed of conversion.

Farmers who do not want to dramatically change the age structure of the herd, but have the misfortune of starting with a very low proportion of A2A2 cows, can use A2 sexed semen to rapidly raise the number of A2A2 calves without changing standard herd management. In future, upcoming conversions may create a demand for A2A2 heifers; hence rearing additional A2A2 yearlings and thereby creating a surplus for sale could be seen as a business opportunity.

Importantly, although sexed semen will increase the proportion of female calves born from 50% to 90%, there will not be any impact on the milking herd until almost three years after the mating decision, when the first A2A2 heifers start producing milk. In addition, one of the implications of having a very high speed of conversion is to end up with a very young herd, that is made up mostly of two, three and four-year-old cows.

6.1.2 A2 beta-casein in the milk

The importance of the composition of cow's milk and the ratio of A1 and A2 beta-casein proteins within the milk can be seen from two different perspectives. First, from a public health perspective, any decision to reduce the exposure to the A1 beta-casein may be beneficial or unlikely to cause harm.

Second, it is a challenge from a branding perspective for the marketing of A2 dairy products, as A2 milk must contain only the A2 beta-casein with no A1 at all.

In practice, the percentage of A2A2 cows in the herd cannot be used to estimate the proportion of the A2 beta-casein in the milk, given that heterozygous (A1A2) cows produce A1 and A2 beta-casein in a 1:1 ratio. Hence, the proportion of A2 beta-casein in the milk will always exceed the proportion of A2A2 cows in the herd. Also, the proportion of A2 beta-casein in milk will be less than the allele proportion in the herd because younger cows produce less milk than older cows. In a non-testing situation, the A1 beta-casein content will halve with each generation, that is, the frequency of the A1 allele drops but the herd will never be free of the A1 beta-casein. In testing situations, the frequency of the allele increases as the herd moves towards A2, but cow's milk will exclusively contain A2 beta-casein only when a herd consists entirely A2A2 cows.

6.1.3 The impact on herd BW

This research utilises the BW Index, which is the predominant system to measure genetic merit in New Zealand dairy cows. Other systems such as New Zealand's Merit Index (NZMI) would lead to similar results as the same principles apply. The model was used to calculate the cost to the dairy industry if it is required to convert the national herd to A2. These calculations are based on the assumption that by going to A2, it will be necessary to not use elite bulls that are A1A1 and A1A2. This may result in financial costs for breeding companies. At a national level, this has the negative effect of narrowing the genetic base of the national herd by selecting from fewer animals.

The frequency of the A2 allele in the current LIC's Premier Sires DNA and Daughter Proven Bull Teams is about 65% for Holstein-Friesian, and between 75% to 80% for the Jersey and KiwiCross™ (LIC, 2013). The high incidence of the A2 allele in elite bulls has some implications. Firstly, it is likely to reduce the decline in the average BW of the Premier Sires, in the case of A1A1 and A1A2 bulls being removed from the team. Secondly, it is an indication that farmers who are not trying to select for A2 are 'accidentally' selecting for A2 at the moment in New Zealand. At an industry level, as a consequence of A2 bulls performing better in bull evaluations than A1 bulls, the incidence of the A2 allele in the national herd is increasing incidentally.

Farmers wishing to use A2 semen but also wanting to use the 'bull of the day' scheme will need to keep in stock straws of frozen A2 semen as a back-up for those days when the semen is not A2. This represents additional cash cost, as frozen semen is more expensive than fresh semen. For an individual farmer at the moment, it is feasible to construct A2 'packs' of semen by breed which

probably involves no loss of BW at all. Indeed, by putting together Premier Sires in packs of 5 bulls it is possible to put together a BW that is even higher than the 'bull of the day' at a slightly higher cash cost. However, the whole industry cannot do this as the numbers required would require famers to select from lower BW bulls.

Importantly, a drop of bull BW will be a function of both the average BW of the 'bull of the day' and the average BW of the additional pack of frozen A2 semen. Assuming a pessimistic scenario in which frozen semen has a BW of 200 and the 'bull of the day' a BW of 240, farmers will not necessarily suffer a drop of 40 BW units. That is, if the 'bull of the day' can be used 60% of the time and the A2 pack of frozen semen is used in the remaining 40% of the time, the drop will be only 16 BW units.

In the hypothetical scenario of converting the national herd, there may be an argument regarding the current active A1A2 elite bulls. There may be some very top bulls that it will not be possible to use anymore over the national herd. However, these bulls will not necessarily be lost; they instead could be mated to some of the top A2A2 cows, and even without using A2 sexed semen, 25% of the progeny will be A2A2 bulls and 25% will be A2A2 heifers. Assuming the A1A2 bulls have a remarkable genetic merit, it is likely that progeny will also be exceptional, providing additional A2A2 animals and contributing to genetic improvement. Importantly, this scenario is possible as the A1/A2 status is mediated by a single gene, otherwise it would not be as easy to avoid narrowing the selection basis.

Herd conversions to A2 may reduce herd genetic gain, however there is a range of counteracting strategies that can be used to minimise this drop. Amongst these are high replacement rates, artificial insemination of yearlings, and the use of A2 sexed semen. As a general statement, the shorter the generation interval the faster the herd BW increases. A high replacement rate reduces the generation interval but at the same time requires more replacements. Artificial insemination of yearlings increases the feasible replacement rate because there are more calves available. Farmers who are really worried about loss of potential BW can artificially inseminate all their yearlings with A2 semen, recognising that their progeny should have the highest BW in the herd. As a result of a very fast conversion, the herd BW will be maximised, but at the cost of a very young herd. These young cows eat less, but also produce less. At an industry level, the use of A2 sexed semen may help to avoid narrowing of the selection basis as there will be fewer bulls needed, albeit at extra cost given that sexed semen is more expensive.

6.1.4 Summary of key findings

A summary of the key findings from this research follows:

• In a non-testing situation, replacement rate has a minimal impact on the rate of herd conversion. The annual rate of progress is about 5%, regardless of the initial proportion of A2A2 cows.

• In a non-testing situation, regardless of the initial A1:A2 allele ratio, both the proportion of A2A2 cows and the A2 beta-casein in the milk increases, with a function that is in the early years almost linear, but subsequently becomes curvilinear and asymptotic.

• Using solely A2 semen with no genetic testing of cows and calves, a pure A2 herd will never be achieved because with each generation the A1 frequency of the allele will only halve.

• Regardless of the initial proportion of A2A2 cows, genetic testing of calves is more effective than genetic testing of cows to speed up a herd conversion process. However, testing of both cows and calves achieves faster herd conversion than doing just one or the other.

• In testing situations, the potential advantages of high replacement rates are only achieved if all of the replacements are A2A2. This may not be feasible in earlier years, particularly if calves are not selected from first-calving heifers.

• Genetic testing of cows allows efficient culling, which has an almost immediate effect on the A2A2 composition of the milking herd. Herd composition will start changing in year two, while with other strategies (e.g. non-testing) there will not be any impact before year three.

• The benefit of artificially mating yearlings with A2 semen is mainly in the earlier years, and the impact is greater in combination with the genetic testing of calves.

• High replacement rates and/or the artificial insemination of yearlings with A2 semen, can compensate for the potential drop in herd genetic gain given by a lower bull BW, by using exclusively A2 bulls.

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