
THE PROCEEDINGS OF THE
NEW ZEALAND SOCIETY
OF
ANIMAL PRODUCTION
VOLUME 62 2002

Comparing herd selection strategies for A2 beta-casein

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Abstract

Herd conversion strategies for A2 beta-casein were investigated within an inter-temporal simulation model with annual time-steps comprising three sub-herds based on allele status (A1A1, A1A2, and A2A2). Cows that are homozygous for the A2 allele of the beta-casein gene are known as A2 cows (A2A2), and produce milk known commercially as 'A2 milk'. The simplest herd conversion process is to use semen from A2A2 bulls. However, the conversion function is curvilinear and asymptotic and this strategy by itself cannot achieve herd purity. Conversion rates can be increased markedly through genotyping of calves and/or cows. This is necessary for completion of the conversion process. Mating of yearlings with A2 semen can have considerable impact, particularly in association with increased replacement rates. Combining these strategies can lead to pure A2A2 herds within 5 to 8 years, depending on initial herd structure. Use of sex-selected semen can further reduce the conversion period. There is potential for reduced cow herd gain in breeding worth as a result of non-use of elite bulls that are not A2A2. For example, a loss of 20 breeding worth units in the bull team would result in ten years being required to achieve breeding worth gains otherwise achievable in nine years.

Keywords: herd selection; A2 milk; A2 beta-casein

Introduction

Herd simulations were undertaken of dairy cow breeding strategies to create herds where all beta-casein within the milk is of the A2-type. Milk that meets this criterion is known as 'A2 milk'. The fundamental rationale for farmers considering herd conversion is current or future market premiums associated with A2 milk being perceived as a healthier alternative (Woodford 2010; Woodford 2011). These claims remain controversial (European Food Safety Authority 2009). However, in this paper the specific health claims are put aside. The aim is to identify the impact of alternative decision processes on herd conversion outcomes for those farmers who, for reasons either of risk management or potential profit, do decide to engage in the process of herd conversion. The analysis builds on earlier decision analyses by Woodford (2007).

The A2 status of bovines is determined by specific alleles of the beta-casein gene found on autosomal Chromosome 6 (Kaminski et al. 2007). The original allele is now known as the A2 allele, with the A1 allele being a historical mutation. Subsequent mutations have led to the B, C, D, F, and G alleles within the A1 family, and A3, E, H1, H2 and I alleles within the A2 family. The key distinguishing feature of beta-casein from within the A1 family of alleles is that the beta-casein protein has the substitution of amino acid histidine for proline at Position 67. The histidine substitution leads on digestion to release of the exorphic opioid peptide beta-casomorphin-7 (BCM7) (De Noni 2008; European Food Safety Authority 2009).

All non-bovine ruminants produce beta-casein of the A2-type, that is with proline at the equivalent position. Human milk is also A2-type. Even within bovine ruminants the A1 family of alleles is only found in cattle of European origin. Prevalence of the A1 allele varies between breeds and countries (Kaminski et al. 2007; European Food Safety Authority 2009). In general, black and white breeds tend to have higher prevalence of the A1 allele than yellow and brown breeds. However, this generalisation cannot be used to predict the allele frequency of individual herds. Most herds within 'Western' countries are likely to have an A1:A2 allele ratio between 1:2 and 2:1.

For a cow to produce A2 milk, that is milk in which all beta-casein is of the A2 type, then the cow has to be homozygous for the A2 allele (A2A2). Heterozygous (A1A2) cows produce A1 and A2 beta-casein in a 1:1 ratio. An A1A2 cow mated to an A2A2 bull will have an equal probability of producing progeny that are either A1A2 or A2A2. Within New Zealand, the A1/A2 status of elite bulls is routinely available. Bull testing is also routine in most other Western countries, although not necessarily reported in marketing materials.

The first key action that farmers face when undertaking herd conversion is to use semen from A2A2 bulls. Other decisions, either in parallel or subsequent, relate to genotyping of calves, genotyping of cows, the desired replacement rate, the mating of yearling heifers with A2 semen, and use of sex-selected semen.

Within New Zealand, it is apparent that there has been a trend to increasing prevalence of the A2 allele across all major breeds within the national dairy herd. The evidence for this has not been formally documented, but it is notable that over the last decade nearly all elite bulls have been either A1A2 or A2A2. This is consistent with evidence that under New Zealand conditions the A2A2 allele is

Table 1 Initial herd age structure.

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

associated with increased breeding worth (Morris et al. 2005). It is likely but unproven that the A2 allele frequency has been increasing since New Zealand moved to measuring genetic merit based on production efficiency rather than maximum production per cow.

Materials and methods

A simulation model was constructed to run in Excel™. The base model was constructed for a ten year time period with annual time steps. Animals progress yearly to the next age group based on two mathematical identity relationships. For any age class, opening numbers plus births plus purchases minus deaths minus sales equals closing numbers. Closing numbers for class m in year t then become opening numbers for class $m+1$ in year $t+1$. Modelling is by age cohort rather than individual animals, and probabilities of various events and outcomes, such as deaths and sex, are applied deterministically to a cohort.

Within any herd undergoing conversion, there will initially be three sub-herds comprising animals that are A1A1, A1A2 and A2A2. Assuming all semen is from A2A2 bulls, all progeny of A1A1 cows will be A1A2 and will therefore enter the A1A2 sub-herd. Half the progeny of A1A2 cows will be A1A2 and half will be A2A2. All A2A2 cows will produce A2A2 progeny.

User-determined model parameters include initial herd age structure, death rates for each class of animal, involuntary culling rate and overall herd replacement rate. The involuntary culling rate relates to conditions such as non-pregnancy or other forms of forced culling. This rate is assumed to be constant across age classes. Discretionary culling is then determined endogenously based on overall replacement rate minus deaths and involuntary culls.

Specific decision rules as to how discretionary culling is applied across the three sub-herds depend on whether cows have been genotyped. In the absence of cow-genotyping for A1/A2 status, cows are culled on age irrespective of their sub-herd. If cows have been genotyped, then cows are first culled from the A1A1 sub-herd, then the A1A2 sub-herd. All remaining cows are assumed culled at the end of their lactation as ten-year-olds regardless of A1/A2 genotype status.

Selection of A2 semen has potential to require use of lower breeding worth bulls owing to non-use of elite bulls that are either A1A1 or A1A2. Accordingly, user-defined parameters include the initial breeding worth for each age class within the breeding herd, together with user-defined breeding worth of the bulls in each year.

Initial herd allele composition is also user-determined. For simulations reported here, three alternative baseline compositions were considered, with initial A2A2 herd compositions of 10%, 25% and 45%, and A1A2 percentages of 45%, 50% and 45%, with the remainder in each run being A1A1 animals. These combinations are consistent with Mendelian allele distribution principles and align with A2 allele frequencies of 33%, 50% and 67% respectively.

For investigations reported here, the initial age structure reflected survival rates as reported in national statistics (DairyNZ 2012), ranging from 86% survival from two to three-year-olds, down to 67% for nine to ten-year olds (Table 1). Other baseline data used in all simulations were 15% involuntary culling across all cow age classes, 5% perinatal loss of calves, 8% deaths between birth and 12 months, and 2% deaths per annum for all other age classes. Initial overall herd breeding worth was set at 77 (DairyNZ 2012), ranging from 21 breeding worth units in 10-year old cows to 110 breeding worth units in one-year heifers. Bull breeding worth ratings were assumed to increase at 10 units per annum.

Figure 1 Proportion of A2A2 cows over a ten year period in three herds with different initial A2A2 proportion (Herd A = 10%, Herd B = 25%, Herd C = 45%) in a non-testing scenario using two different replacement rates (RR).

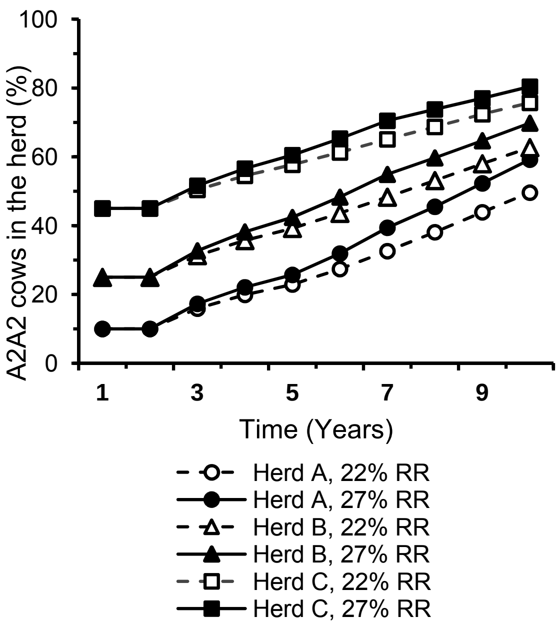


Table 2 Proportion of A2A2 cows after ten years and time (years) to achieve a pure A2A2 herd for alternative management scenarios, and different initial A2A2 herd proportions (Herd A = 10%, Herd B = 25%, Herd C = 45%). Nf = Non-feasible replacement rate given the other stated decisions strategies.

Management scenario			Herd A		Herd B		Herd C	
Testing strategy	Replacement rate (%)	Yearlings to 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	50	>15	63	>15	76	>15
		Yes	54	>15	66	>15	78	>15
	27	No	59	>15	70	>15	80	>15
		Yes	65	>15	74	>15	83	>15
	32	No	Nf	Nf	Nf	Nf	Nf	Nf
		Yes	73	>15	80	>15	87	>15
Testing of cows	22	No	53	>15	68	>15	83	>15
		Yes	57	>15	71	>15	85	>15
	27	No	76	15	95	12	100	10
		Yes	80	14	97	12	100	10
	32	No	Nf	Nf	Nf	Nf	Nf	Nf
		Yes	97	13	99	11	100	10
Testing of calves	22	No	74	>15	91	15	99	12
		Yes	93	14	99	12	100	10
	27	No	63	>15	75	>15	87	>15
		Yes	96	13	100	10	100	8
	32	No	Nf	Nf	Nf	Nf	Nf	Nf
		Yes	96	12	100	10	100	9
Testing of cows and calves	22	No	79	14	95	11	100	10
		Yes	95	11	100	10	100	9
	27	No	82	13	99	11	100	9
		Yes	100	9	100	8	100	6
	32	No	Nf	Nf	Nf	Nf	Nf	Nf
		Yes	100	8	100	7	100	5
Testing of cows and calves, using sexed semen (90% female)	22	No	99	11	100	10	100	9
		Yes	100	10	100	10	100	9
	27	No	100	9	100	7	100	6
		Yes	100	8	100	7	100	6
	32	No	100	8	100	6	100	5
		Yes	100	7	100	6	100	5
	37	No	100	9	100	7	100	6
		Yes	100	6	100	5	100	4
	42	No	Nf	Nf	Nf	Nf	Nf	Nf
		Yes	100	6	100	5	100	4
	47	No	Nf	Nf	Nf	Nf	Nf	Nf
		Yes	100	6	100	5	100	4

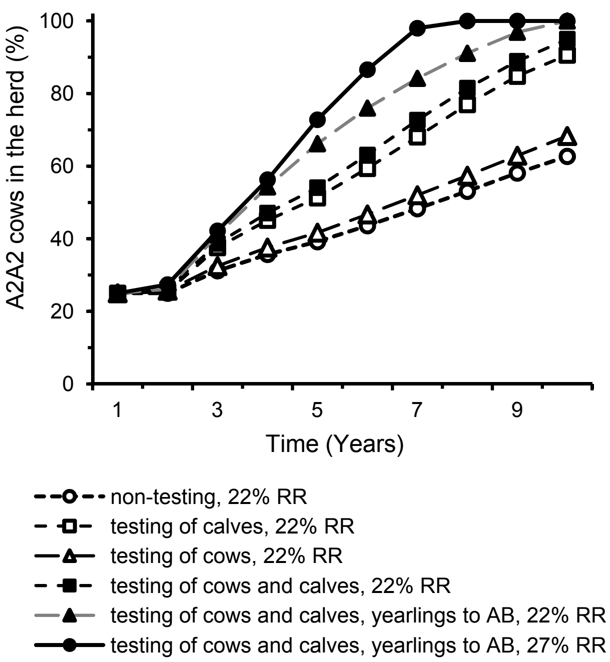
Once a decision is made to use only A2 semen then at least two years and nine months elapse from initial herd conversion decisions before there is any impact in the milking-herd. In practice, there could be anything up to a further 11 months after the initial decision, depending on when the decision to convert is made relative to time of mating. In results reported here, with times reported in full years, it is assumed that the first calves to A2 semen are born one year after the conversion decision is made. Accordingly, if, for example a herd status is reported as being after '*x*' years, then this is '*x*' years after the conversion decision is made, and '*x-1*' years from the birth of the first calves to A2 semen.

Results

Progress based on use of A2 semen but no genotyping of animals

Following the initial two years as the first crop of heifers join the milking herd, and assuming a 22% replacement rate, the percentage of A2A2 cows increases thereafter at approximately 5% per annum for Herds A and B but at under 4% for Herd C (Figure 1). In the early years the function is close to linear but the long term function is curvilinear with declining slope, and without genotyping a pure herd will never be achieved.

Figure 2 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. RR = Replacement rate.



A1A1 cows will be eliminated from the herd once all of the foundation cows have been culled. However, without genotyping of cows and/or calves there will always be some A1A2 cows, with this percentage approximately halving for each future cow generation, defined here as the inverse of the replacement rate. In general, higher replacement rates will speed up the conversion process. This benefit is maximised where there is low involuntary culling of young cows. In this non-testing situation, mating of yearling heifers with A2 semen can further speed up the conversion process because this heifer group will have a higher incidence of the A2 allele than the older cows (Table 2). Mating of heifers also provides scope for higher replacement rates and hence reduction of generation interval.

Genotyping

Genotyping can be undertaken for calves or cows or both. Testing of calves is necessary to maximise efficiency of calf selection for the A2 allele, given that A1A2 cows can pass on either the A1 or the A2 allele. Although the testing of cows is necessary to maximise culling efficiency, the effectiveness of this is determined more by the discretionary culling rate, that is the replacement rate minus deaths and involuntary culls, rather than the overall replacement rate. In all situations, genotyping of calves is more effective than genotyping of cows, and leads to rapid achievement of pure A2A2 status (Table 2).

Whereas mating of yearlings can be effective at all replacement rates, increasing the replacement rate is relatively ineffective in the absence of yearlings mated to A2 semen (Table 2).

Farmers wishing to maximise the rate of herd conversion could combine genotyping of calves, genotyping of cows, mating of yearling heifers with A2 semen, and high replacement rates. Given an initial allele ratio of 1:1 and with 25% of cows initially A2A2, then a pure A2A2 herd can be achieved within seven years of the herd conversion decision (Figure 2).

Sex-selected semen

The use of sex-selected semen (90% female) is the most powerful decision option to speed up conversion of a herd to A2. Depending on the initial herd structure, it is possible to produce a pure A2 herd within four years of the mating decision, albeit with a herd that is predominantly of two and three-year-old cows.

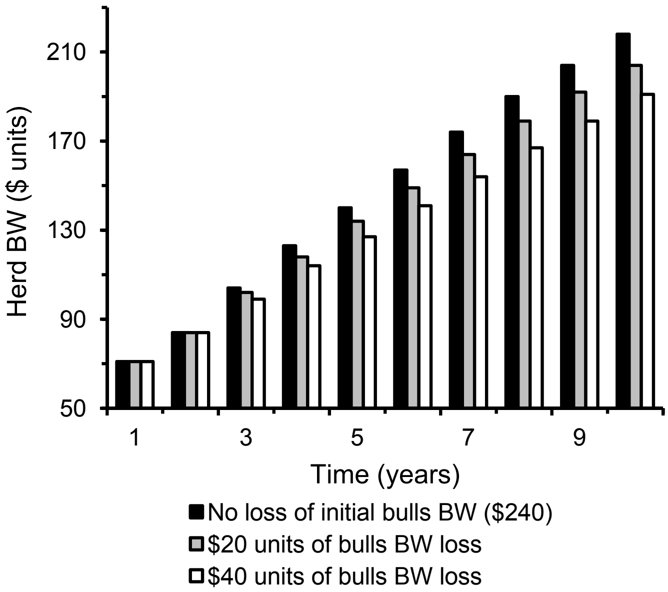
A2 beta-casein in the milk

The proportion of A2 beta-casein in the milk will reflect A2 allele frequency in the herd rather than the percentage of A2A2 cows, but mediated somewhat by the lower milk production of two-year-olds. Accordingly, the proportion of A2 beta-casein in the milk will always be greater than the herd proportion of A2 cows given that A1A2 cows also produce some A2 beta-casein. Assuming an initial A2 allele frequency of 50%, then in a non-testing situation, but also depending on other decision choices, the A2 beta-casein proportion in the milk will increase after three years, initially at about 4% per annum, but with a function that is curvilinear and asymptotic. In testing situations, the increase can be considerably greater and remain linear through to herd purity.

Effects on breeding worth

The breeding worth of an average New Zealand dairy herd was 77 in 2012 with this index increasing each year by eight to ten units as younger cows of higher breeding worth replace older cows of lower breeding worth (DairyNZ 2012). This is driven by the breeding worth of the teams of elite breeding bulls used across the national herd. Any decision to use exclusively A2A2 bulls inevitably means the non-use of some bulls that would otherwise be available. Currently, it is possible in New Zealand for individual farmers to purchase semen from nominated sires without decreasing the overall breeding worth of their bull team. However, if all farmers were to use only A2A2 bulls then there would be a decline in the average breeding worth of bulls. The extent of the lowered breeding worth would depend on the breed, given that the proportion of elite bulls that are A2A2 varies between breeds. Accordingly, two hypothetical situations are modelled here, with the average breeding worth of the bull team lowered 20 and 40 breeding worth units respectively (Figure 3). If 20 units are sacrificed, then

Figure 3 The effect on herd genetic gain breeding worth (BW) units ($) for alternative scenarios of bull breeding worth loss of $20 or $40 breeding worth units, from using only A2 semen, in a non-testing scenario with a replacement rate of 25% involving 15% involuntary culling rate and 2% death rate.



it would take ten years to achieve the genetic gain that could otherwise be obtained in nine years. If 40 bull breeding worth units are sacrificed then it would take ten years to achieve what could otherwise be achieved in eight years.

Discussion

The simplest herd conversion strategy is to use only A2 semen. However, this approach by itself will never achieve a pure herd. Rather, it can position a farmer to subsequently complete the process through testing of cows and calves. In that context, it can be seen as an initial risk and option management strategy.

Most New Zealand farmers naturally mate their yearling heifers and do not keep the replacements. However, artificial insemination with A2 semen could be a valuable strategy, particularly in a testing situation and in the initial years to ensure all replacement calves are A2A2. Higher replacement rates are important to reduce the generation interval, but the main benefits of these replacement strategies are only achieved when used in conjunction with strategies to ensure all replacements are A2A2 calves. High replacement rates have reduced impact in situations where involuntary culling is high and hence discretionary culling is low.

Converting a herd to A2 may reduce the potential rate of genetic gain in the herd measured by breeding worth, as a consequence of non-use of elite bulls that are either A1A2 or A1A1. Nevertheless, there is a range of potential counteracting strategies. For example, selecting herd replacements from first-calving heifers, and an increased replacement rate, will each provide compensatory genetic gain. It is notable that the modelled potential gain in cow breeding worth of approximately 13 units per annum, even with a loss of 20 units of bull breeding worth, is considerably more than the average annual gain of eight to ten breeding worth units on New Zealand dairy farms that is achieved currently by most New Zealand farmers. There is scope for further modelling of these relationships.

Some caution is appropriate in recommending generic strategies given the range of farming situations. Optimal decisions strategies will be determined by future premiums for A2 milk, the costs of genotyping, and the costs of sex-selected semen. However, for farmers who simply wish to keep their options open, then a positioning strategy of using A2 semen could be considered appropriate. For those farmers who are serious about the conversion process, then use of A2 semen plus testing of all female calves could be considered the minimum set of strategies. Additional strategies to be assessed, based on the specifics of individual farm situations, include testing of cows, selecting replacements from first-calving cows and an increased herd replacement rate. Sex-selected semen is a particularly powerful option for those who wish to maximise the speed of conversion, albeit at increased semen cost. Although McMillan and Newman (2011) have shown that sex-selected semen is currently not economic in most dairy situations, this may not apply in future for some specific farmer situations in relation to A2 beta-casein herd conversion, with the key determinant being the extent of the milk price premium.

Acknowledgements

This paper reports investigations undertaken by the senior author as part of a postgraduate scholarship at Lincoln University funded by the New Zealand Ministry of Foreign Affairs and Trade.

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