# Opportunities for Genetic Selection to Increase Milk Quality

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## Take Home Message

- The true value of milk depends upon its composition and its end use.
- The value of milk to the producer depends upon its true value and the payment system adopted by the industry.
- Altering the composition of milk by genetic means can be achieved by selection, crossbreeding and transgenic approaches.
- The impact of within-breed selection on the quality of milk is affected by the relative emphasis placed on milk quality compared to other attributes that comprise the selection objective.
- The chosen selection criteria for milk quality and the genetic and environmental relationships between these measured attributes and the traits in the selection objective will influence the rate of progress in milk quality.
- Artificial breeding organisations rather than farmers control the three most important of the four selection pathways.
- Breed changes can have major influence on milk quality but the choice of breed is usually dominated by attributes other than milk quality.
- Transgenic modification of the genome offers quantum leaps in milk quality but requires further research, education and testing in order to gain consumer acceptance.
- Segregation of cows with different milk quality into separate herds offers an immediate opportunity to modify milk quality. This potential is yet to be exploited to any significant extent.
- The long-term nature of genetic improvement with its associated time delays necessitates that progress will only be achieved when the future

needs of consumers is in concert with today's vision shared by producers, processors and AB companies.

## ■ The Value of Milk

In a co-operative industry, the true farm gate value of milk to the producer is determined by the value of the milk in terms of the products that are manufactured from it, less the costs of transporting, manufacturing and marketing. Generally, the processing value of the milk is considerably less than the value of milk used for fluid sales. However, the market for fluid sales is limited by the size and consumptive nature of the local population. The value of processed milk varies according to the product mix created from the milk and from the composition of the milk as this determines potential yields of products. The true value of representative milk from some breeds and crosses in New Zealand are shown in Table 1 according to the end use of the milk.

**Table 1. The true values (NZ$/kg) of representative milk from various breeds present in New Zealand when 10% or 70% of milk is sold in fluid form with the remaining milk fraction processed in alternative product mixes.**

| Fluid Milk | Residual | Breed | | | | | |
|---|---|---|---|---|---|---|---|
| | | Average | Holstein | Holstein-Friesian | Jersey | Ayrshire | Crossbred HF ´ J[1] |
| **10%** | Cheese | 0.371 | 0.320 | 0.356 | 0.428 | 0.362 | 0.377 |
| **10%** | Channel mix[2] | 0.338 | 0.291 | 0.324 | 0.390 | 0.328 | 0.343 |
| **70%** | Cheese | 0.587 | 0.543 | 0.574 | 0.635 | 0.578 | 0.593 |
| **70%** | WMP[3]-Cheese | 0.581 | 0.536 | 0.568 | 0.630 | 0.572 | 0.586 |

[1] HF = Holstein-Friesian and J = Jersey.
[2] Channel mix was whole milk powder 30%, skim milk powder 25%, cheese 22% and casein/butter 23%.
[3] WMP = whole milk powder.

## ■ Payment Systems for Milk

The value of milk to the producer depends upon the value of milk to the industry and the payment system adopted by the processors. Some alternative single- and multiple component payment systems are shown in Table 2 (adapted from Garrick and Lopez, 1999). The multiple component payment systems are derived on the basis of the marginal value of each component, scaled so that the true value of average milk is equal to the value predicted from the payment system. The current payment system adopted in New Zealand rewards producers on the basis of milkfat and protein yields less a volume-based penalty. The payment system sends price signals to the producer in relation to milk quality attributes.

**Table 2. Payment systems (NZ$/kg) based on various components[1] devised from the average New Zealand milk in two market and processing scenarios.**

| Fluid milk | Residual | Single components | | | | FPV | | | FPLV | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | VO | FO | PO | FPO | F | P | V | F | P | L | V |
| **10%** | Channel mix[2] | 0.338 | 7.222 | 9.555 | 4.113 | 3.039 | 6.863 | -0.047 | 2.777 | 6.271 | 0.706 | -0.047 |
| **70%** | WMP-Cheese[3] | 0.581 | 12.423 | 16.437 | 7.075 | 6.322 | 8.862 | -0.028 | 5.770 | 8.087 | 1.132 | -0.028 |

[1] F = yield of fat, P= yield of protein, L = yield of lactose, V = volume of milk, VO = volume of milk only, FO = yield of fat only, PO = yield of protein only, FPO = yield of fat plus protein only, FPV = yields of fat and protein with a penalty for volume of milk, FPLV = as FPV with yield of lactose included.
[2] Residual milk, after meeting fluid milk demand, was used for whole milk powder 30%, skim milk powder 25%, cheese 22% and casein/butter 23%.
[3] Residual milk, after meeting fluid milk demand, was used for whole milk powder 50% and cheese 50%.

True values of milk from a range of breeds, along with the values estimated from various payment systems derived from average milk are shown in Table 3 (adapted from Garrick and Lopez, 1999). More complex payment systems provide a fairer system of reward whereas simple systems tend to under- or over-value certain milks. However, increasing the number of components in a payment system may divert the emphasis producers place on the most valuable milk component. Ideally, producers should be educated to consider milk in terms of its aggregate value, rather than in terms of its composition for one or two components. More complex systems have the disadvantage of increasing the cost to the processor of evaluating the value of milk as supplied.

**Table 3. True and estimated values (NZ$/kg) of various milks assessed by different payment systems[1] derived from average milk for a market using 10% milk for fluid demand[2].**

| Milk | True Value | Single components | | | | Multiple components | |
|---|---|---|---|---|---|---|---|
| | | VO | FO | PO | FPO | FPV | FPLV |
| **New Zealand average** | 0.338 | 0.338 | 0.338 | 0.338 | 0.338 | 0.338 | 0.338 |
| **Holstein** | 0.291 | 0.338 | 0.253 | 0.306 | 0.276 | 0.279 | 0.284 |
| **Holstein-Friesian (HF)** | 0.324 | 0.338 | 0.317 | 0.326 | 0.321 | 0.320 | 0.322 |
| **Jersey (J)** | 0.390 | 0.338 | 0.417 | 0.383 | 0.402 | 0.404 | 0.398 |
| **Ayrshire** | 0.328 | 0.338 | 0.315 | 0.335 | 0.323 | 0.326 | 0.327 |
| **Crossbred HF ´ J** | 0.343 | 0.338 | 0.346 | 0.343 | 0.345 | 0.345 | 0.344 |

[1] VO = volume of milk only, FO = yield of fat only, PO = yield of protein only, FPO = yield of fat plus protein only, FPV = yields of fat and protein with a penalty for volume of milk, FPLV = as FPV with yield of lactose included.
[2] Residual milk, after meeting fluid milk demand, was used for whole milk powder 30%, skim milk powder 25%, cheese 22% and casein/butter 23%.

## Improving Milk Value by Selection

Selection is a simple and effective method of improving animal performance. The development of an effective selection scheme begins with the specification of a goal. In circumstances where the goal is profit focussed, the formation of a selection objective is a logical consequence of the goal, and involves two discrete steps. First, the traits that influence the goal need be identified. This is typically straightforward and includes those traits that influence income, or costs. Second, the relative economic emphasis of each trait in the list must be determined. This is a much more problematic process as it requires knowledge of production, management and economic circumstances. Milk characteristics that influence the true value of the milk but are not part of the payment system will typically be overlooked by producers. For example, in New Zealand, the colour or hardness of the milkfat can contribute to the value of the resulting dairy products manufactured from the milk. However, neither colour nor hardness are part of the current payment system. Colour and hardness differ markedly between the two major dairy breeds, namely Friesian and Jersey cattle (Winkelman et al, 1999; MacGibbon, 1996). Recent evidence suggests that the concentration of CLA (conjugated linoleic acid) in milk influences its pharmaceutical properties (Kelly and Bauman, 1996). The level of CLA could therefore influence the value of the milk in the marketplace. (See paper by Bell and Kennelly in this Proceedings). Concentrations of CLA are not currently accounted for in evaluating the value of milk.

The usual approach to dairy cattle improvement makes use of four pathways of selection. These represent the parents of replacement cows and the parents of replacement artificial breeding bulls. The corresponding pathways are the selection of cows to breed cows (CC), bulls to breed cows (BC), cows to breed bulls (CB) and bulls to breed bulls (BB). Dairy farmers choose the cows from which to retain replacements, and the bulls to mate to these cows. However, the choice of bulls to mate to these cows is typically only among the subset of bulls that artificial breeding (AB) companies choose to make available to farmers. In this case, it makes little difference to genetic progress as to which bull an individual farmer chooses to use to sire his replacements. In the absence of sexed semen usage, artificial breeding companies choose the cows from which to purchase bull calves, and may also choose the sires of those calves. Producers retain the resulting offspring if female, or sell the offspring if male to AB companies. In this circumstance, AB companies control the bull parent pathways. Accordingly, provided a farmer uses herd testing and artificial breeding, and is prepared to sell bull calves to AB companies, the control of the rate and direction of genetic gain rests principally with the AB companies.

Given a list of traits with defined economic emphasis, animals can be ranked for the objective, provided they can be evaluated for each of the traits in the objective. This requires that measurements be undertaken for each trait or for associated characteristics. In respect to milk quality, the gross composition of fat and protein are readily assessed from modern equipment. More detailed discrimination of milk quality requires knowledge of certain aspects of the fat, protein or carrier fractions of the milk. For example, the fat colour, fat hardness, chain length or saturation of the fat fraction, or the casein, whey and non-protein nitrogen fractions of the protein can be obtained. Many of these measures require larger samples of milk than are obtained for traditional herd test procedures. Comparatively time consuming and expensive laboratory techniques are also often required. The response to selection will be determined by the attributes that are measured on each cow, their genetic and environmental relationships and their emphasis in an aggregate index (Gibson 1987; 1989).

Following herdtesting, producers can rank their cows on the basis of productivity and cull the low performers. This practice has almost no impact on the rate or direction of genetic gain, but does influence the genetic lag or difference in merit between the cows in the herd and the team of AB bulls.

The manner in which the AB company chooses bull fathers, bull mothers and makes proven bulls available is crucially important to industry. An AB company could influence the quality of milk by including quality aspects in their selection strategies. However, a major determinant of the profitability of AB companies arises from market share. In a competitive environment the most important factor that influences the market share is the ranking of the bulls on the basis of progeny test performance. Such performance is typically limited to type and gross aspects of milk composition including milk yield, fat and protein concentration. These traits are often used to produce an index of type and milk value. In these circumstances there is little incentive for AB companies to use selection to improve milk quality beyond those characteristics influencing the index. The index construction is usually dictated by the milk payment system.

The direction and nature of the breeding programme involves the three-way interaction between producers, the artificial breeding companies and the processors that determine the payment system. The actions and vision of all three of these parties must be in concert if milk quality is to be favourably changed by selection.

## ▪ Improving Milk Value by Crossbreeding

Different breeds of cattle produce different yields of milk that grossly vary in the concentration of particular components (Table 4). Furthermore, the nature of the fat fraction and the protein fractions may vary between breeds. Cattle of different breeds usually differ in many other attributes, such as coat colour, temperament, reproductive performance, meat and carcass attributes, size, weight and stature. The choice of breed by producers often includes many aspects other than their revenue from milk. Producers have opportunities to alter milk quality by changing breeds, by crossbreeding, or by introgression of favourable genes from one breed to another.

**Table 4. Liveweight and productive performance of different breeds of dairy cattle in New Zealand (Livestock Improvement, 2000).**

| | Days in milk | Milk (L) | Fat | | Protein | | Liveweight (kg) |
|---|---|---|---|---|---|---|---|
| | | | (kg) | (%) | (kg) | (%) | |
| **Holstein-Friesian** | 215 | 3,803 | 166 | 4.4 | 131 | 3.5 | 450 |
| **Jersey** | 220 | 2,791 | 161 | 5.8 | 113 | 4.1 | 355 |
| **Crossbred FxJ** | 217 | 3,445 | 170 | 5.0 | 127 | 3.7 | 420 |
| **Ayrshire** | 218 | 3,452 | 151 | 4.4 | 122 | 3.6 | 417 |

Changing breeds and crossbreeding will not be successful in practice if it is driven from the viewpoint of one aspect of animal performance, such as milk quality, without considering the aggregate performance as influenced by the entire spectrum of attributes associated with the breed or cross (Table 5). Complementarity of characteristics from two or more breeds may favour a crossbred individual, but somewhat surprisingly, producers in many countries have a marked preference for purebred breeds of dairy cattle. Introgression can be achieved by crossing breeds with disparate performance for a particular characteristic, followed by successive backcrossing in concert with selection of those individuals that have retained the favourable characteristic. However, there are few if any examples in the developed world of deliberate introgression of genes for milk quality in dairy cattle.

**Table 5. Average economic indexes for profit per 4.5 tonnes dry matter for the next generation (Breeding Worth or BW) and the remaining lifetime (Production Worth or PW) of cows from different breeds of dairy cattle in New Zealand (Livestock Improvement, 2000).**

| **Breed** | **BW**[1] | **PW**[2] |
|---|---|---|
| Holstein-Friesian | 70 | 80 |
| Jersey | 81 | 101 |
| Crossbred FxJ | 86 | 109 |
| Ayrshire | 51 | 58 |

[1]The economic weights for BW are currently $1.18 per kg milkfat, $3.50 per kg protein, -$0.049 per litre volume, -$0.49 per kg liveweight and $0.029 per day longevity. These economic weights represent the influence of the traits on future profit, not income. Annual updates of these weights and the corresponding PW weights are available at www.aeu.org.nz

[2]Production Worth includes permanent environmental influences and, in the case of crossbred animals, the relevant heterosis.

## ■ Improving Milk Value by Transgenesis

The quality of milk should be amenable to improvement by transgenic modification, such as may result from increasing the copy number of genes affecting favourable characteristics, knocking out genes responsible for unfavourable characteristics or introducing novel gene sequences that have been identified from inspection of milk in other species (Karatzas and Turner, 1997). For example, increasing the casein concentration of milk by duplicating the casein gene may improve milk quality. Removing β-lactoglobulin from cows milk using a gene knock-out would result in cows milk that was more closely comparable to human milk which does not contain β-lactoglobulin (Wall et al, 1997). The introduction of new genes, such as those that code for the lactase enzyme may result in more concentrated milk and reduce the energy requirements used by the cow in the synthesis of lactose. The creation of pharmaceutical products harvested in milk, such as $\alpha_1$-antitrypsin, may create opportunities for improving the health of some sectors of the human population.

At present, the production of transgenic products, particularly milk, is viewed negatively by some sectors of the population. This is not surprising, given the current inadequacy of education and debate relating to these technologies. Similar negative reactions were apparent with the introduction of vaccines, electricity, milking machines and artificial breeding. It is likely that these practices will ultimately be accepted, provided appropriate research and controls are put in place.

## ■ Improving Milk Value by Segregation

Many genetic variants relating to milk attributes are known to exist in the cow population. Obvious examples include the milk proteins such as α–, β–, κ–caseins and β-lactoglobulin. Some of the properties of these variant milks with respect to their processing and product attributes are already known. In some cases one variant is not universally favourable relative to another, but is desirable when the milk is used for certain purposes. In this case, there would be no interest in systematically altering the gene frequency in the population. With respect to two alternative alleles present at a particular locus, cows will exhibit one of three different phenotypes. If the milk from these three types of cows could be harvested and processed separately, there may be economic advantages. Considering the variants known to exist at several different loci, there are dozens of existing phenotypes exhibited by animals that could relatively easily be exploited.

Segregation of milk is probably not practical within a single herd, but could be achieved if cows were allocated to herds according to their genotype (or phenotype) for particular milk characteristics. The segregated milks could thus be designed for particular processing and end-product niches. Such designer milks are yet to be exploited on a wide sale despite the knowledge of some of these variants and effective tests for them having been available for many years. Achieving designer milks in the short term requires co-ordination between producers and processors. Some AB companies have made available information as to the variant genotypes of their bulls for some time.

## ▪ Obstacles to Selection for Increase Milk Value

Preference for a particular breed involves a large number of attributes, with coat colour, size and temperament all playing a significant role in addition to production, reproduction, longevity and milk quality. Producers are often reluctant to change to breeds that are not already accepted among their neighbours. Most of the developed world's dairy industry is now based on a Holstein monoculture. Non-traditional breeds with favourable milk characteristics will not be adopted in these circumstances.

The recent Holsteinisation of the world appears to have been driven by their undisputed superiority in producing high volumes of milk in markets that reward these high volumes of milk. However, their typically lower concentrations of milkfat and protein, and their higher maintenance requirements erodes their apparent advantage when comparison is based on profitability per unit of feed, particularly in payment systems that penalise volume, such as occurs in New Zealand. In these perhaps unique circumstances, the most profitable cows can represent a range of breeds and their crosses, providing opportunities to exploit breed differences in milk quality that may not exist in other parts of the world.

Dairy cattle improvement is traditionally based around the widespread use of elite sires that have previously been progeny tested. Matings between elite cows (CB) and elite bulls (BB) in 2001 will produce bull calves in 2002. These calves will undergo semen collection as yearlings and are typically two years of age when their progeny test daughters are born. The bulls are therefore four years of age when their progeny test daughters begin their first lactation. The five-year old bulls with superior daughters on the basis of their first lactation are widely used, producing their widespread use daughters as six-year old bulls in 2008. These daughters will produce milk from 2010 up to perhaps 2020. Today's market signals are therefore influencing the nature of milk produced from 2010 onwards. Improving the future quality of milk therefore requires market signals available today, in concert with technological and other developments that have yet to occur.

Selection will typically progress when there is concordance between product value, payment for raw materials, and animal indexing. In practice, market failure often occurs, most notably when simplified payment systems are adopted. Consequently, the producers do not receive true market signals as to the components that influence their long-term returns. Accordingly, these components will not be appropriately represented in the economic indexes of aggregate merit used to rank candidates for selection as parents of the next generation. The entire chain from consumer preference to animal ranking and choice must be intact in order for selective advance in milk quality. An inadequacy in any step of this chain can render the process inoperative.

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