

Altering Milk Composition Through Genetic Selection

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ABSTRACT

The genetic relationships among carrier, fat, protein, and lactose will allow genetic alteration in any direction desired, although some changes would be much easier than others. Genetic parameters may vary somewhat between different populations, thus affecting the rates of different directions of change. In general, however, selection for an alteration in the fat:protein ratio would proceed rapidly, principally through alteration of fat concentration. Genetic alteration of composition is likely only if economic incentives for such change exist. Economic values, and therefore selection pressure, should be applied to amounts of components rather than concentrations. Recent developments in the theory of deriving economic weights for animal breeding indicate that selection indexes need to be reassessed. Although optimum breeding goals will vary somewhat, in most circumstances fat and protein yields and concentrations and the fat:protein ratio are likely to increase due to genetic selection. Only in the unlikely situation that fat has a very small or negative economic weight are other changes indicated. Lactose concentrations are unlikely to change much in any situation. Genetic variation in the composition of fat and protein, while of biological interest, is unlikely to be of more than minor importance in genetic improvement.

INTRODUCTION

Milk is the raw material of a major processing industry. In Canada, for example, only 35%

of the milk produced is consumed as fluid milk, and of that 35% is processed to standardize its composition and improve its shelf life. Increasingly, milk is seen not as an entire product but as the sum of its constituent parts. It is natural then to ask, does the composition of milk meet our requirements and, if not, can we alter its composition?

The composition of milk prior to processing might be altered by various changes of management, probably nutritional (28), or by altering the genetic potential of our dairy cattle. The role of the geneticist might be seen as simply describing the various possible types of, and methods of achieving, different genetic alterations to milk composition. In isolation, such an approach is inadequate. Genetic change is likely only if there is a financial incentive for such change. It is the way in which the financial incentives interact with the mechanisms for genetic change that determines which genetic changes are likely to come about.

There are three broad routes potentially available for genetic change in dairy cattle: 1) utilization of genetic differences between breeds, by breed crossing or substitution; 2) utilization of genetic variation within breeds, by selection; and 3) creation of new genetic variation, using the new transgenic technologies. The present paper deals principally with selection within breeds, although between breed variation will be mentioned briefly. Many of the issues raised are illustrated with examples for the Canadian dairy market, but the principles apply to most dairy markets. The potential for transgenic modification of milk composition is discussed elsewhere (2, 4, 15).

Much of the processing of milk is applied to, and most genetic and economic information is available for, the major components of milk: carrier, fat, protein, and lactose. The present discussion therefore focuses primarily on these major components. However, the composition of the fat and protein fractions of milk might

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TABLE 1. Composition of the milk of five dairy breeds.¹

Breed	Milk yield (kg)	Concentration of constituents		
		Fat	Protein (g/kg)	Lactose
Holstein-Friesian	7073	37.0	31.1	46.1
Ayrshire	5247	39.9	33.4	46.3
Jersey	4444	51.3	38.0	47.0
Guernsey	4809	48.7	36.2	47.8
Brown Swiss	5812	41.6	35.3	48.0

¹From Wilcox et al. (31) except lactose (13).

themselves be altered, and this is dealt with briefly.

DISCUSSION

Material for Genetic Change

Existing genetic variation provides the material for genetic change, be it between or within breeds. Variation in milk composition between the main dairy breeds under similar conditions is shown in Table 1. Most variation is in fat concentration, with less in protein concentration, and very little in lactose concentration. Protein and fat concentration are highly correlated across breeds. Nevertheless, the fat to protein ratio varies from 1:0.84 (Holsteins) to 1:0.74 (Jerseys), giving some scope to choose among breeds should the incentive be there.

A suggested summary of various literature estimates of variation within breeds was given by Gibson (6), taken largely from Majjala and Hanna (18), and is presented in Table 2. As with any set of average values, the individual estimates contributing to the average vary widely among sources. Some caution must be exercised when using the parameters in Table 2. Parameters for different traits come from varying numbers of estimates, with only six data sets contributing to protein and three to lactose. Although heritabilities for liquid and fat from data sets including lactose were in line with literature averages, those including protein gave heritabilities considerably above average for liquid and fat yield. This suggests that protein yield might generally have lower heritability than liquid and fat yield, which is in line with more recent estimates. Much of the variation among estimates of heritabilities between

data sets is probably due to different methods of estimation and statistical sampling errors (18). Much of the remaining variation might be due to the observed relationship between heritabilities and production (12).

The effect of production on genetic correlations does not appear to have been studied. However, since the heritabilities of all yield traits appear to be equally affected by production (12), it is possible that genetic correlations are not affected. Nevertheless, there may well remain real differences between populations in genetic correlations. For example, Table 3 shows the estimates of population parameters found recently for Holsteins in Quebec, Canada (5). These estimates of genetic correlations and the heritability for protein are considerably lower than the literature averages. Thus, while the estimates in Table 2 should provide an approximate starting point when specific information is not available, actual parameters may differ among populations.

Direct Selection for Altered Composition

A number of publications have dealt with various methods of directly or indirectly selecting for altered milk composition [summarized in (6)]. essentially, selection could alter milk composition in almost any direction desired, although some changes would be markedly easier than others. In general, it appears that selection for an altered fat:protein ratio would proceed relatively quickly and would be achieved principally through increasing or decreasing the fat concentration (31). Perhaps more interestingly, Kennedy (16) found that it would be possible to reduce fat concentration markedly while making close to the maximum possible response in protein yield and with modest gains

TABLE 2. Phenotypic and genetic correlations, heritabilities, and coefficients of variation of major milk constituents.^{1,2}

Traits	CV	Yields				Concentrations (conc.)		
		Y	F	P	L	f	p	l
Liquid yield (Y)	.22	<u>.27</u>	.82	.87	.96	-.27	-.18	.01
Fat yield (F)	.24	.88	<u>.24</u>	.86	.67	.26	-.11	.20
Protein yield (P)	.23	.95	.93	<u>.27</u>	.81	.04	.22	.00
Lactose yield (L)	.31	.96	.75	.87	<u>.25</u>	-.36	-.29	.29
Fat conc. (f)	.09	-.20	.24	-.01	-.18	<u>.47</u>	.55	.22
Protein conc. (p)	.08	-.19	-.04	.06	-.35	.49	<u>.48</u>	-.07
Lactose conc. (l)	.07	.21	.31	.06	.47	.11	-.56	<u>.28</u>

¹Genetic correlations above, phenotypic below, and heritabilities on the diagonal (underlined).

²Adaptations of literature averages taken from Gibson (6).

in protein concentration. Given its low coefficient of variation and modest heritability, the rate of change of lactose concentration in any selection scheme will be slower than that possible for fat and protein.

Limits to Genetic Alteration of Milk Composition

Given that various genetic changes in composition are possible, are there likely to be any limits to such change? Physiological and nutritional work with dairy cattle is unlikely to provide an answer, since such work is carried out within the confines of existing genotypes. As an example, one can cite the widely held belief that lactose concentration is constant because it osmotically drives water secretion. Yet, there is genetic variation in lactose concentration within breeds (Table 2). Moreover, many species of mammal have lactose concentrations very different from those of dairy cattle (13).

Interspecies variation in milk composition can be seen as the equivalent of a genetics experiment on a vast scale. Many millions of

years of evolution have produced mammalian species with a variety of milk compositions, presumably at least in part reflecting different adaptive strategies. Summaries of the differences between species compiled by Jenness (13, 14) and plotted graphically in Figures 1 and 2 [taken from (6)], indicate very few if any constraints on milk composition. Fat concentration varies among species from almost 0 to 55%, protein from almost 0 to 16%, and lactose from 0 to 8%. Fat and protein concentrations are positively correlated and both fat and protein concentrations are negatively correlated with lactose concentration but with very wide variations about these general relationships.

Gibson (6) also plotted the energy concentration of the milk against size-scaled total lactation milk energy yield for 12 species of mammal (Figure 3). There is no evidence of any relationship. Although more data would be useful, there is no available evidence to suggest that selection for milk of high energy density would be biologically antagonistic to high output per animal.

TABLE 3. Phenotypic and genetic correlations and heritabilities among yields of milk components for Holstein cattle in Quebec.^{1,2}

	Carrier	Fat	Protein	Lactose
Carrier	<u>.29</u>	.54	.80	.93
Fat	.75	<u>.31</u>	.66	.55
Protein	.88	.80	<u>.20</u>	.78
Lactose	.94	.62	.81	<u>.25</u>

¹Genetic correlations above, phenotypic below, and heritabilities on the diagonal (underlined).

²From de Jager and Kennedy (5) except parameters for lactose, which are modified from those in Table 2 to bring into line with the generally lower correlations among other traits.

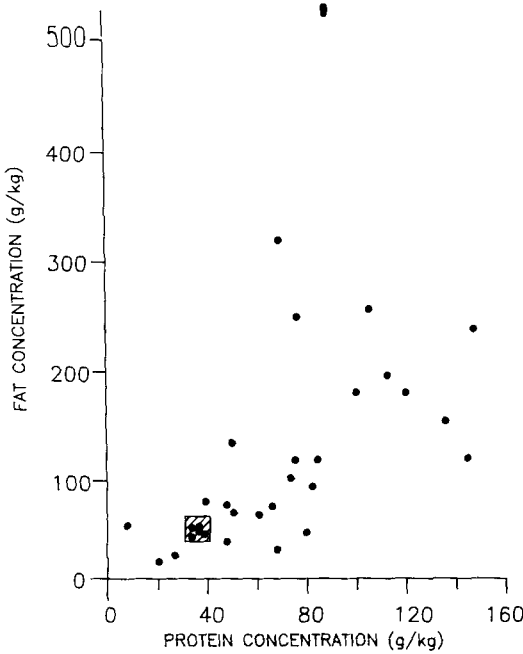


Figure 1. Plot of fat concentration against protein concentration in the milk of representatives of 17 orders of mammal. Shaded box indicates approximate range among breeds of dairy cattle. Data from Jenness (14).

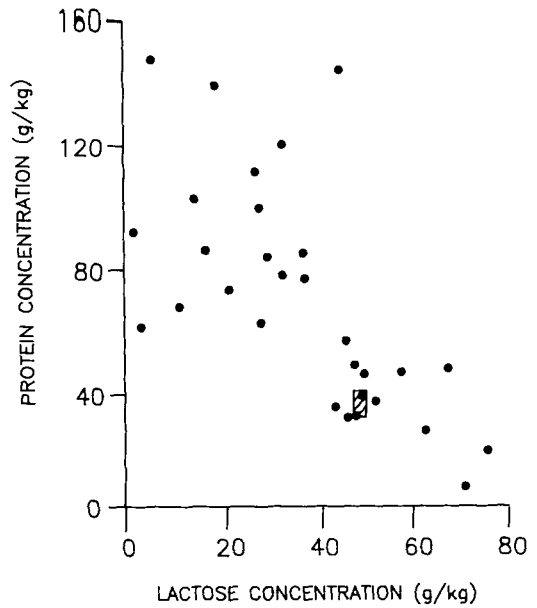


Figure 2. Plot of protein concentration against lactose concentration in the milk of representatives of 17 orders of mammal. Shaded box indicates approximate range among breeds of dairy cattle. Data from Jenness (14).

Incentives for Genetic Change

Although many types of genetic change in milk composition are possible, in practice genetic change is likely only if there are incentives for such change. An obvious incentive would be a disparity between supply and demand for milk components. For example, analyses of the British milk market (3, 6) have shown that the market is oversupplied with protein and undersupplied with fat. Gibson (6) concluded that the milk of Holstein-Friesian cattle in Britain would have to increase in fat concentration from 3.9 to 5.6%, holding protein concentration constant, to balance market requirements for these components. In Canada, recent analyses of supply and utilization (7) indicated that the market is balanced for fat production, that 10% of nonwhey milk protein is sold at greatly reduced prices, and that 45% of the lactose is discarded or disposed of at minimum possible cost due to excess production. An analysis of the US dairy market (33)

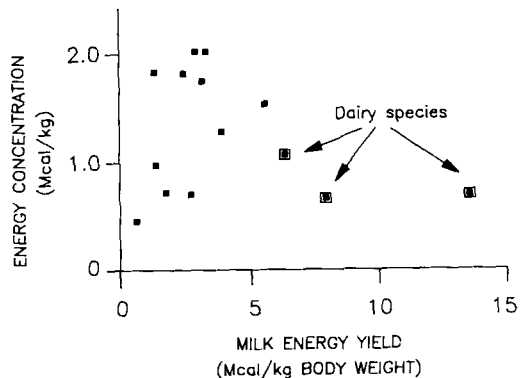


Figure 3. Plot of energy concentration of the milk against size-scaled lactation energy yield for 12 species of mammal. From the right, the three most extreme points are for the dairy species, goat, cattle and sheep. Data same as used by Taylor (27).

indicated that, excluding whey proteins, supply and demand of fat and protein were in approximate balance but that lactose was in massive excess. In all cases an altered milk composition is called for, but the optimum composition differs between markets. These and other considerations are dealt with by Hettinga (11).

A disparity between supply and demand might suggest the need for genetic change in milk composition without supplying the economic incentive. Decisions on dairy cattle breeding are taken by farmers and the breeding companies and cooperatives who serve them. Thus, the primary economic incentive for genetic change will be in the prices the farmer receives for the milk components.

Selection Indexes

Where several traits are to be improved simultaneously, the optimum genetic change is made by use of a linear selection index, as suggested by Smith (26) and Hazel (10). The selection index takes into account the relative economic value (economic weights) of each trait of economic importance, the phenotypic covariances among the traits in the index, and the genetic covariances between the traits in the index and those of economic importance. In a given dairy cow population with given phenotypic and genetic parameters, the optimum selection index, and hence the optimum genetic change, will depend on the economic weights of each of the milk components.

Concentration or Yields?

Pricing systems vary considerably within and between markets. Although some systems pay for volume with corrections based on various solids concentrations, all methods of payment can be expressed in terms of price per unit weight of each component (7). Each component has intrinsic value related to amount rather than concentrations, similarly for the costs of producing and processing components. Moreover, construction of selection indexes based on concentrations rather than yields leads to unnecessary difficulties in handling the resulting nonlinearity (32). There does not appear to be any cogent reason for attributing direct value to, or to selecting for, milk composition per se. Rather, milk has value related to the

amounts of each component and any genetic changes in milk composition will be a consequence of selection for the amounts of components secreted.

Derivation of Economic Weights

The economic weights used in calculating a selection index are the economic values of unit genetic improvement in each trait. Clearly, economic weights should allow for both the returns and costs of increased outputs. Beyond this, there needs to be a recognition that there are restraints on total output due either to saturated markets (e.g., US) or legislated quotas on production (e.g., Canada and Western Europe).

Smith et al. (25) argued that since animal breeding is a medium to long-term exercise, all costs of a livestock enterprise are variable costs. They also argued that increases in output achieved genetically could be achieved by other means (by rescaling the size or number of operations). Thus, economic returns from genetic increases in output should be rescaled accordingly. Their argument does not require that the market be saturated but is most easily understood in this situation, since any increase in output per animal will have to be accompanied by a decrease in the total number of animals.

The method of Smith et al. (25) started with a profit equation of the form:

$$P = R - C$$

where returns (R) and costs (C) are continuous functions of any number of traits and are subject to proportional scaling as the number of animals is altered (i.e., no fixed costs). They showed that the economic weight of trait Y, E^Y , after rescaling to fixed total economic output, is given by:

$$E^Y = \frac{C}{R} \frac{\delta R}{\delta y} - \frac{\delta C}{\delta y} \quad [1]$$

Without rescaling, the economic weight would be:

$$E^Y = \frac{\delta R}{\delta y} - \frac{\delta C}{\delta y} \quad [2]$$

Thus, economic weights after rescaling will be lower than without rescaling (since $C < R$).

TABLE 4. Economic weight for carrier, fat, protein, and lactose for average values in the Canadian market with different costs and methods of rescaling.¹

Costs ² included	Method of rescaling used	Economic weight			
		Carrier	Fat	Protein	Lactose
		(\$/\sigma_p)			
None	None	0	223.6	180.3	10.9
f	None	0	182.3	162.5	-9.0
f + m	None	-31.0	180.9	161.7	-10.1
f + m + p	None	-45.1	167.6	154.4	-15.7
f + m + p	Volume	-95.8	165.4	152.6	-18.6
f + m + p	Fat	-45.1	109.7	154.4	-15.7
f + m + p	Returns	-45.1	136.4	129.2	-17.2

¹Phenotypic standard deviations (σ_p) for carrier, fat, protein, and lactose were taken to be 938.9, 40.2, 34.2, and 54.0 kg.

²f = Feed, m = management, p = processing costs.

The relative economic weights of different traits will also be altered. It was shown that the economic weights defined by Equation [1] are equivalent to those for increasing the economic efficiency of production.

Provided that quotas are not thought to be permanent, Equation [1] would also provide appropriate long-term economic weights where quotas are operated. If, for political and economic reasons, the quota system has long-term stability, a different form of scaling is appropriate. For the general case where the quota operates on trait x, the economic weight of any trait which is a component of x, was shown by Gibson (7) to be:

$$E_y = \frac{\delta R}{\delta x} - \frac{\delta C}{\delta x} - \frac{P}{X} \quad [3]$$

where X is the total production of trait x. Economic weights for the remaining traits, not constrained by quota, would be given by Equation [2].

Economic Weights in the Literature

A review of literature up to 1986 (6) found that although various economic weights for milk components had been suggested, few included any costs and none included all costs or considered rescaling. All the indexes reviewed would therefore overvalue genetic improvement and would probably produce suboptimal relative genetic changes in the various components.

Van Arendonk et al. (29) made a careful study of the breeding opportunities in the Dutch market, with quotas on milk production. They developed a method of deriving economic weights, specific to their situation, which was a special case of the general method—Equation [3] suggested by Gibson (7).

Gibson (7, 8) examined the results of using different methods to derive economic weights for dairy cattle in Canada. Table 4 illustrates the effect of sequentially including various costs and then rescaling, when the original values assigned to each milk component are estimates of their average value, based on utilization in the Canadian market and export sales. The appropriate economic weights in this case would be those including all costs and scaled to fixed returns. Inclusion of feed, management, and processing costs reduces absolute and alters relative economic weights. Rescaling further reduces absolute economic weights with different methods producing different relative economic weights.

Effects of Different Methods of Deriving Economic Weights on Selection Responses

Theoretical studies of the behavior of selection indexes (24, 30) have indicated that rather large changes in economic weights do not always produce correspondingly large changes in selection responses. For this reason, Gibson (8) examined the effects of different methods of calculating economic weights of milk components in Canada on the responses to selection.

TABLE 5. Responses to sire selection with intensity 1.0 for various definitions of economic weights when prices correspond to average Ontario industrial payments.¹

Basis of economic weights		Correlated responses				Apparent economic response	Efficiency ³
Costs included ²	Method of rescaling	Carrier	Fat	Protein	Lactose		
		cell;		$(\sigma_p)^4$			
None	None	.381	.465	.298	.306	184.7	.936
f	None	.383	.463	.292	.302	154.1	.934
f + m	None	.363	.475	.285	.284	141.4	.596
f + m	Volume	.255	.502	.235	.289	107.2	1.00
f + m	Fat	.417	.434	.297	.327	92.2	.882
f + m	Returns	.353	.479	.277	.272	94.6	.965

¹After a study by Gibson (8).

²f = Feed, m = management; processing costs are included directly in payments.

³Economic weights with all costs included and scaled to fixed volume are optimum, because quota operates on volume.

⁴Phenotypic standard deviations.

In a given situation, one set of economic weights may be considered to be correct (e.g., for the examples in Table 4, the weights including all costs and scaling to fixed returns are considered the most appropriate). Use of these economic weights to construct a selection index will, by definition, result in the maximum economic response to selection. The economic efficiency when using alternative economic weights is the economic response to selection expressed as a proportion of the maximum economic response and is always less than 1.0.

For the economic weights given in Table 4, no method of derivation resulted in an economic efficiency of less than .97. However, larger effects on efficiency were found for other pricing systems. Table 5, adapted from Gibson (8), shows the results when the payments for components correspond to the method of paying for industrial milk in Ontario, where a farm quota on milk volume is operated. Losses in economic efficiency of up to 12% were observed when inappropriate methods of deriving economic weights were employed. However, the most striking differences are those in apparent economic response, which indicate that failure to include costs and to rescale leads to overestimation of economic gains from selection by more than 72%. In other cases, overestimates of more than 100% were observed (8). If all costs were included but rescaling was not

employed, economic gains were overestimated by 25 to 32%.

Pathways to Genetic Improvement

In addition to expected differences in rates of genetic change, different pathways of genetic improvement can lead to different relative genetic changes, as illustrated in Table 6. Here, the use of optimum selection indexes for sire selection (based on 50 half-sib first lactation records) and individual selection (single lactation record) are contrasted for the optimum economic weights in Table 4. Population parameters were those used by Gibson (8), similar to those in Table 3. The selection intensities have been standardized so that the same genetic response of fat yield is made in both cases. Although both pathways give increases in fat and protein yields and concentrations, the relative rate of increase of concentrations is markedly lower for sire selection than for individual selection. Thus, the relative genetic changes in milk composition depend on the structure of the breeding population, as well as economic weights and phenotypic and genetic population parameters.

Realistic Genetic Changes in Milk Composition

As has been demonstrated, the majority of published indexes for milk components are

TABLE 6. Response of milk components to index selection of sires and individuals when economic weights are based on average component values in Canada, accounting for all costs and scaling to fixed returns.^{1,2}

Selection pathway	Correlated response						
	Carrier				Individuals		
	Carrier	Fat	Protein	Lactose	Fat	Protein	Lactose
	(kg)				(%)		
Sires	454	40	21	22	.42	.09	-.09
Individuals	88	40	12	9	.75	.20	.09

¹Phenotypic and genetic parameters are similar to those given in Table 3.

²Selection intensity adjusted so that 40-kg increase in fat yield is achieved in both pathways.

based on incorrect economic weights and do not therefore provide reliable estimates of likely changes in milk composition. Van Arendonk et al. (27) used appropriate methods for the Dutch dairy market, with a pricing system giving equal value to fat and protein and a quota on milk volume. They found, for four types of farming enterprise (production and costs varied), that optimum indexes would tend to increase fat yield marginally faster than protein yield. Fat and protein concentrations would increase only very slowly.

Gibson (8) examined genetic responses from selection on sires with 50 effective daughters and from selection on individuals with a single lactation record. The economic weights considered most appropriate for various pricing systems in the presence or absence of various quotas always resulted in genetic increases in fat and protein yields and concentrations and an increase in the fat to protein ratio. This, despite economic values for protein varying from close to that for fat to being negative. However, the rates of change, particularly of fat and protein concentrations and fat to protein ratio, varied considerably. Both increases and decreases of lactose concentration were observed, but such changes were always small.

Gibson (8) considered both individual and sire selection, while Van Arendonk et al. (27) considered sire selection, the pathway which contributes most to dairy cattle improvement in practice. However, simulations of different dairy cattle breeding strategies using appropriate economic weights, and selection indexes are clearly called for.

Gibson (6), in reviewing the literature, suggested that in most situations both fat and protein yield would receive positive economic

weights and that all possible combinations of positive economic weights would yield similar selection responses. This proposition is examined more closely in Table 7. The response to sire selection for economic weights which differ in relative weighting of fat and protein are given for both literature averages (Table 2) and Canadian (Table 3) population parameters. The calculation of the efficiency of selection assumes that economic weights of 1.0 for both fat and protein are correct.

Losses in efficiency are less severe for literature average than Canadian population parameters. But even for the literature average parameters, with economic weights greater than zero for protein and fat, losses in efficiency of selection range as high as 8%. This is a large economic loss when summed over the whole population. If either fat or protein has large negative economic weights, losses in efficiency are severe.

From the correlated responses of milk components, any index with a substantial positive economic weight for fat will cause increased fat:protein ratios. Decreased fat:protein ratios can occur with small (literature parameters) or negative (Canadian parameters) economic weights for fat. Somewhat different responses are seen if different economic weights of carrier and lactose are considered (not shown here). However, the negative value for carrier and zero value for lactose are likely to reflect the true values for these components as pricing systems for milk components evolve.

As noted earlier, the literature parameters probably overestimate the heritability of protein, so that responses in practice are likely to be more similar to those for the Canadian parameters. For the variety of realistic economic

TABLE 7. Responses to index selection of sires with intensity 1.0 for different relative economic weights for fat and protein for literature average and Canadian estimates of phenotypic and genetic population parameters.

Fat	Economic weights (σ_p) ¹		Correlated responses (σ_p)			Economic efficiency ²
	Protein	Carrier	Fat	Protein	Lactose	
Literature parameters						
1.0	-.5	.079	.273	.066	.014	.423
1.0	0	.316	.419	.355	.244	.921
1.0	1.0	.382	.409	.442	.323	1.000
0	1.0	.345	.341	.455	.304	.940
-.5	1.0	.200	.145	.358	.195	.600
Canadian parameters						
1.0	-.5	-.013	.408	.030	.014	.611
1.0	0	.135	.489	.186	.154	.889
1.0	1.0	.281	.474	.319	.276	1.000
0	1.0	.278	.301	.368	.267	.830
-.5	1.0	.092	-.146	.200	.080	.429

¹Economic weights for carrier and lactose are -.25 and 0 in all cases.

²Assumes that economic weights of 1.0 for fat and protein are optimum.

weights (7, 29), fat always retained a substantial positive economic weight, while protein could take positive or negative economic weights in different situations. Thus, genetic decreases of the fat:protein ratio seem highly unlikely in practice.

Composition of Fat and Protein

There is genetic variation in the composition of milk fat (6). However, conflicting requirements for different processes and the ability of technology to overcome minor variations in fat composition [given less restrictive legislation (1)] mean that genetic manipulation of fat composition is unlikely to be cost effective.

Considerable attention has been focused on milk protein polymorphisms and their effects on milk yield and composition (17, 20, 21, 22) and on cheese making properties (19, 23). In most cases, those alleles that have been associated with higher milk yields, fat, and protein production are already close to optimum gene frequencies and provide little opportunity for genetic gain (17, 20, 21, 22). Schaar et al. (23), in a small experiment, found that the *B* allele of β -lactoglobulin was associated with a substantial increase in cheese yield, due to increased casein concentration in the milk. However, much larger studies (20, 22) found only small differences in casein concentration associated

with this allele. When the apparent dominance of the *B* allele of β -lactoglobulin is taken into account, gene frequencies appear close to optimum. Smaller, but still useful, differences in cheese yield associated with different genotypes at the β -casein and κ -casein loci were found by Marziali and Ng-Kwai-Hang (19), which indicated that some genetic improvement might be possible.

As with the principal milk components, any selection on the composition of milk protein will be driven by economic incentives. Genetic changes in milk composition that improve cheese manufacture will probably not benefit other sectors of the industry. Because genetic improvements in cheese yield or speed of cheese making (23) are typically small (in economic terms), and cheese manufacture is only a portion of the whole industry, the overall benefits of genetically manipulating protein composition are likely small. For example, a 5% ultimate gain in cheese yield by manipulating protein polymorphisms, as suggested by Graham et al. (9), in addition to likely being an overestimate (6), would have to be set against potential increases in overall efficiency of milk production by conventional selection of the order of 9% per generation. Nevertheless, as accurate information on the effect of protein polymorphism accumulates, information on protein polymorphism might usefully be included in a selection index, with the overall objective of

improving the economic efficiency of milk production.

Conclusions

Although genetic alteration of milk composition is certainly possible, changes achieved in practice will depend upon the economic incentives for change. The incentives will generally be the pricing system for milk and the quota system, if any. These incentives have to be translated into economic weights for use in selection indexes. Because the principal objective of genetic change is increased economic efficiency of production, selection should be directed to output traits not composition per se.

The methods used for deriving economic weights have, until recently, been inappropriate. Consequently, there is rather little reliable information about expected genetic changes of milk composition. But, under a wide range of conditions the trend will likely be for increased yields and concentrations of fat and protein and probably an increased fat to protein ratio. Exact changes will depend on the phenotypic and genetic parameters, the economic incentives, quota systems, and breeding strategies applicable to a given population.

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