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Appropriate selection indices for functional traits in dairy cattle breeding schemes

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Abstract

The objective of this study was to establish different single or multiple trait selection indices to calculate genetic and economic gains by combining some production, reproduction and udder health traits in a population similar to the overall practical situation in Iran, with and without imposing restrictions on genetic change for some traits. The SelAction software was used to perform the analyses based on selection index theory through a deterministic model. Results indicated that among established indices, the index that showed the highest genetic gain for milk yield did not maximize the total genetic and economic gains. Rather, the index that included all production, reproduction and udder health traits yielded the highest genetic and economic gains. When we placed restriction on the selection indices, the economic gain decreased and the amount of reduction depended on the heritability and the correlation of restricted trait(s) with other traits. Generally, regarding the economic genetic gain per generation, the indices based on records of 200 offspring were 4.819% more efficient than those that used information of 100 offspring.

For a long time, selection in dairy cattle was mainly based on milk yield in many countries. Recently, an index has been presented that, in addition to the milk yield, includes milk composition and herd life (Sadeghi-Sefidmazgi et al. 2009). Some countries implemented more complex indices which also include functional traits such as resistance to diseases, fertility and even temperament and carcass traits (Miglior et al. 2005). Functional traits play an important role for farm profit. Additionally, the increasing demand for organic products and concerns regarding animal welfare also enhanced the importance of functional traits in breeding goals.

The major principle in animal breeding is the selection of superior animals (e.g. based on genetic potential or economic merit) and their mating in order to produce a superior next generation. If breeding values are predicted with higher accuracy and precision, the real selection differential would be higher and consequently there would be higher response to selection. Since implementation of any program imposes some costs, in order to predict outcomes of different breeding programs, simulation can be used either to reduce the probability of an inaccurate decision or to select an optimum program which maximizes the profitability. There are two general approaches for simulation, deterministic and stochastic, each of which has its own advantages and disadvantages. For example, deterministic models give expected responses and do not consider stochastic variation in response (Dekkers, 2003). However, deterministic simulations are computationally less demanding than stochastic ones. Another advantage of deterministic models is that due to computational ease it is possible to run many programs in order to compare them.

Several studies have shown an effect of considering functional traits in populations of dairy cows, either with stochastic or with deterministic models (Sørensen et al. 1999; Lassen et al. 2007; Fuerst-Waltl et al. 2016; Sneddon et al. 2016). However, only a few studies simulated the population structure of dairy cows in Iran (Sadeghi-Sefidmazgi et al. 2012; Ghiasi et al. 2013), and in general, the number of simulation studies considering a broad range of different traits in the breeding system is not high. Therefore, this research is the first study that simulates concurrently production, reproduction and health traits under current situation of dairy cattle breeding in Iran. In addition, few studies implemented restriction on selection indices in the breeding programs of dairy cows. Since parameters (i.e. genetic and phenotypic correlations and economic values) are population-specific, it seems necessary to investigate the possibility of considering different functional traits in selection indices in different countries. Therefore, the aims of the present study were to: (1) establish different selection indices combining different production, reproduction and udder health traits and compare them based on genetic and economic efficiency in the progeny testing programs with different number of offspring

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per sire using deterministic simulation and (2) simulate restricted indices in order to monitor genetic and economic responses to selection for different traits.

Materials and methods

Several selection strategies were established in order to compare them in terms of genetic and economic responses to selection. Studied traits were 305-d milk yield (Milk), 305-d protein yield (Pro), 305-d fat yield (Fat), days to first service (DFS), calving interval (CI), mastitis (Mast) and somatic cell score (SCS). Selection indices included from only one trait to combination of different subsets of traits based on theories of selection index and restricted selection index (Hazel, 1943; Kempthorne & Nordskog, 1959). Aggregate genotype was as follows:

$$H = (V_1 \times \text{Milk}) + (V_2 \times \text{Pro}) + (V_3 \times \text{Fat}) + (V_4 \times \text{DFS}) + (V_5 \times \text{CI}) + (V_6 \times \text{Mast}) + (V_7 \times \text{SCS})$$

where V_i was the economic value of i^{th} trait. Genetic parameters used in this study were estimated from records of 27714 first lactation cows in five large herds (Chegini, 2017; unpublished doctoral thesis). Estimated economic values adopted from recent studies in Iran (Sadeghi-Sefidmazgi et al. 2011, 2012; Ghiasi et al. 2013) are presented in Table 1.

The software package SelAction (Rutten & Bijma, 2001) was used for simulation and comparison of different indices with regard to response to selection. SelAction uses a deterministic approach based on selection index theory.

At first, an overlapping population structure was considered. This means that individuals from different age classes exist in the population and can mate to each other. In this situation, the optimum selection method is to define a distinct index for each age class, since they have different source of information. For example, younger animals have less information relative to other groups (Rutten & Bijma, 2001). The maximum age of sires and dams were considered to be eight years. Time interval between different age classes was one year and bulls and dams were at least two years old when their first offspring was born. Therefore, parents of the future generation could not be selected from age class one since these animals did not reproduce yet. Each year, 28 sires and 700000 dams were selected as the parents of the next generation. Annual culling rates for sires and dams were 15 and 20%, respectively. Calving interval was considered to be 400 d; therefore, each cow produces 0.91 calves per year. Calf sex ratio was 0.52 to 0.48 for male to female; hence, each cow produces 0.47 male and 0.44 female calves each year.

Information used for evaluation of animals in different age classes were: (1) for sires: sire and dam best linear unbiased prediction (BLUP) breeding values for age classes 1 and 2; sire and dam BLUP breeding values, observations on half-sib and mean estimated breeding values (EBV) of the dams of half sibs for age classes 3 and 4; in addition to the latter information, observations on progeny was used for age class ≥5, and (2) for dams: sire and dam BLUP breeding values for age classes 1 and 2; for higher age classes, in addition to sire and dam BLUP breeding values, information on animal's own performance, observations on half sibs and mean EBV of the dams of half sibs were used. Also, the progeny tests were based on daughter group size of 100 or 200.

SelAction needs genetic and phenotypic (co)variance matrices to establish selection indices. These matrices should be positive definite, meaning that their eigenvalues should not be ≤0. A singular matrix cannot be inverted and used for simulation of traits. Therefore, a method that can transform matrices to positive definite would be useful, as long as most of correlations between traits are close to original estimates (Schaeffer, 2014). The eigenvalues of the genetic and phenotypic (co)variances matrices were calculated using MATLAB 7.8.0 software (Mathworks, 2009a). Obviously, with increase in number of traits, it is more probable that these matrices would not be positive definite, as in our case. To solve this problem, a transformation method which was presented by Schaeffer (2014) was used. The genetic (co)variance matrices before and after transformation are shown in Table 2.

Scenarios of breeding strategies

Scenario 1

In this strategy, 15 different selection indices were established based on aggregate genotype. In addition to the investigation of genetic and economic trends, the aim of constructing these numbers of indices was to compare them in terms of both simplicity and efficiency. Aforementioned indices were as follows:

$$I_1 = (b_1 \times \text{Milk})$$

$$I_2 = (b_1 \times \text{Milk}) + (b_2 \times \text{Fat})$$

$$I_3 = (b_1 \times \text{Milk}) + (b_2 \times \text{Fat}) + (b_3 \times \text{Pro})$$

$$I_4 = (b_1 \times \text{Milk}) + (b_2 \times \text{Fat}) + (b_3 \times \text{Pro}) + (b_4 \times \text{CI})$$

$$I_5 = (b_1 \times \text{Milk}) + (b_2 \times \text{Fat}) + (b_3 \times \text{Pro}) + (b_4 \times \text{DFS})$$

$$I_6 = (b_1 \times \text{Milk}) + (b_2 \times \text{Fat}) + (b_3 \times \text{Pro}) + (b_4 \times \text{CI}) + (b_5 \times \text{DFS})$$

$$I_7 = (b_1 \times \text{Milk}) + (b_2 \times \text{Fat}) + (b_3 \times \text{Pro}) + (b_4 \times \text{Mast})$$

$$I_8 = (b_1 \times \text{Milk}) + (b_2 \times \text{Fat}) + (b_3 \times \text{Pro}) + (b_4 \times \text{SCS})$$

$$I_9 = (b_1 \times \text{Milk}) + (b_2 \times \text{Fat}) + (b_3 \times \text{Pro}) + (b_4 \times \text{Mast}) + (b_5 \times \text{SCS})$$

$$I_{10} = (b_1 \times \text{Milk}) + (b_2 \times \text{Fat}) + (b_3 \times \text{Pro}) + (b_4 \times \text{CI}) + (b_5 \times \text{DFS}) + (b_6 \times \text{Mast})$$

$$I_{11} = (b_1 \times \text{Milk}) + (b_2 \times \text{Fat}) + (b_3 \times \text{Pro}) + (b_4 \times \text{CI}) + (b_5 \times \text{DFS}) + (b_6 \times \text{SCS})$$

$$I_{12} = (b_1 \times \text{Milk}) + (b_2 \times \text{Fat}) + (b_3 \times \text{Pro}) + (b_4 \times \text{CI}) + (b_5 \times \text{DFS}) + (b_6 \times \text{Mast}) + (b_7 \times \text{SCS})$$

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Table 1. Economic values of the studied traits

Trait	Economic value ($)
305 d milk yield (kg)	0.2†
305 d milk protein (kg)	−1.02‡
305 d milk fat (kg)	1.36‡
Days to first service (day)	−2†
Calving interval (day)	−2.5†
Mastitis	−80§
Somatic cell score	−36§

†Ghiasi et al. (2013).
‡Sadeghi-Sefidmazgi et al. (2012).
§Sadeghi-Sefidmazgi et al. (2011).

$$I_{13} = (b_1 \times \text{Milk}) + (b_2 \times \text{CI}) + (b_3 \times \text{Mast})$$

$$I_{14} = (b_1 \times \text{Milk}) + (b_2 \times \text{CI}) + (b_3 \times \text{SCS})$$

$$I_{15} = (b_1 \times \text{Milk}) + (b_2 \times \text{CI}) + (b_3 \times \text{Mast}) + (b_4 \times \text{SCS})$$

where traits are shown in abbreviation and b_i was the index weights which were calculated as:

$$b_i = \mathbf{P}^{-1}\mathbf{G}\mathbf{v}$$

where **P** was the phenotypic (co)variance matrix, **G** was the genetic (co)variance matrix between traits in the selection index and traits in aggregate genotype, and **v** was the vector of economic values. The SelAction software calculates economic response of each trait by multiplying genetic response of the trait by its economic value.

Scenario 2

In this strategy, index weights were obtained based on the theory of restricted selection index. The aim was to maximize response to selection for the aggregate genotype provided that no change for Pro and Mast would occur. The constructed indices in this section were similar to index 12 which was the most complete index, with the difference that restriction was imposed on some traits. The traits (Pro and Mast) which had negative economic values and positive genetic correlation with Milk were individually restricted. The economic values of these traits were allocated such that resulted in response to selection equal to zero for the corresponding traits.

Scenario 3

Two indices similar to index 12 were implemented in this section, with the difference that multiple trait restriction was imposed (e.g. for Mast and Pro or CI and DFS, simultaneously).

Results and discussion

Scenario 1

Expected genetic gains for each trait in aggregate genotype, estimated using different selection indices, are shown in Table 3 and online Supplementary Table S1. Based on this scenario, genetic trend for Milk was favourable (regarding to the moderate h^2 and economic value of Milk). The highest trend for Milk was observed in the index which only included Milk (index 1). However, an unfavourable trend was estimated for Mast and fertility traits. Similar results were obtained using indices that included Fat and Pro (indexes 2 and 3), in addition to Milk. These indices led to more unfavourable trend for fertility traits (Table 3 and Supplementary Table S1). This is probably due to the fact that fertility traits have higher genetic correlation with milk composition than with milk yield. On the other hand, increase in milk composition can cause more negative energy balance (Buttchereit et al. 2011) that subsequently might affect on ovarian activity and reproductive performance.

Inclusion of fertility traits in the indices resulted in considerable increase in total economic response. Not including functional traits (health, fertility, calving ease, udder health, milking speed, type and etc.) in the index, in spite of including in aggregate genotype, resulted in 8–35% decrease in genetic trend based on monetary unit in previous researches (Fewson & Niebel, 1986; Christensen, 1998; Lindhe & Philipsson, 1998; Sørensen et al. 1999; Sölkner et al. 2000) depending on index structure and the used method. Willam et al. (2002) calculated genetic and economic trends for different selection programs that included production and functional traits such as fertility and somatic cell count. Their results showed that inclusion of functional traits in the total index had positive effect on annual genetic gain, because selection based on total index was led to increase of 11 and 17% in genetic gain in terms of monetary unit for Simmental and Brown-Swiss cows, respectively. Among established indices, the indices 1 and 12 had the highest and lowest genetic gains for Milk, respectively (Table 3 and Supplementary Table S1). Using deterministic simulation, Sneddon et al. (2016) predicted annual response to selection for milk, fat and protein as 54.92, 2.22 and 1.78 kg, respectively, by selection based on breeding worth. Also, they reported favorable trend for merit traits. In another recent investigation by Fuerst-Waltl et al. (2016), expected selection response for milk, fat and protein yield were 325 kg, 12.55 and 9.7 per generation in Austrian Simmental cows, respectively.

The indices 12 and 2 had the highest and lowest total economic responses, respectively. Also, the highest and lowest deterioration for reproductive traits was for indices 2 and 12, respectively. Comparison of indices 4 and 6 indicated that including DFS in the index, in addition to the CI, led to considerable improvement in reproductive performance. However, as response to selection reduced for production traits, improvement in total economic merit would not be greatly increased. Also, including DFS as the only fertility trait in the index would not stop unfavorable response to selection for these traits. Predicted downward trend for fertility traits is due to unfavorable genetic correlation with production traits. Similar results were obtained by Gonzalez-Recio et al. (2006) and Ghiasi et al. (2013). The best and worst indices for udder health traits were 12 and 1, respectively. Comparing indices 7, 8 and 9 with the index 3 indicated that including udder health traits in the index caused some improvement for these traits and also for fertility traits due to genetic correlation with fertility traits. Also, comparing indices that considered Mast as the only criterion for udder health traits (7, 10 and 13) with those indices that included only SCS (8, 11 and 14) indicated that there is no significant difference in total economic response. However, indices that included both Mast and SCS (9, 12 and 15) improved economic efficiency compared

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Table 2. Heritabilities (on diagonal) as well as genetic (above diagonal) and phenotypic† (below diagonal) correlations before and after (in parentheses) transformation of variance–covariance matrix

Traits	Milk	Pro	Fat	DFS	CI	Mast	SCS
Milk	0.206 (0.206)	0.900 (0.900)	0.640 (0.640)	0.250 (0.250)	0.300 (0.300)	0.560 (0.546)	0.050 (0.0499)
Pro	0.805	0.183 (0.183)	0.630 (0.630)	0.280 (0.280)	0.310 (0.310)	0.430 (0.419)	−0.120 (−0.1198)
Fat	0.690	0.800	0.130 (0.130)	0.290 (0.290)	0.420 (0.420)	0.390 (0.380)	−0.180 (−0.1798)
DFS	0.020	0.050	0.050	0.080 (0.080)	0.900 (0.900)	0.280 (0.273)	0.190 (0.1896)
CI	0.110	0.240	0.190	0.370	0.098 (0.098)	0.550 (0.536)	0.440 (0.439)
Mast	−0.070	−0.030	−0.040	0.020	0.110	0.010 (0.011)	0.350 (0.355)
SCS	−0.130	−0.090	−0.040	0.040	0.060	0.220	0.044 (0.044)

†Matrix of variance-covariance for phenotypic correlations was positive definite.
Milk, 305-d milk yield; Pro, 305-d protein yield; Fat, 305-d fat yield; DFS, days to first service; CI, calving interval; Mast, mastitis; SCS, somatic cell score.

to indices with only Mast or SCS (7, 8, 10, 11, 13 and 14). Generally, there was an unfavorable response to selection for Mast which is due to its high genetic correlation with production traits and low heritability. The aim of constructing the last three indices (13, 14 and 15) was to investigate the efficiency of simple indices which only include one trait from each subset of traits in comparison to complete index (index 12). The average efficiencies of simple indices in case of 100 and 200 offspring per sire in progeny test were lower than the complete index as 2.67 and 2.61%, respectively. On average, economic gain was 4.8% higher when 200 offspring per sire were used compared with 100 offspring per sire for progeny test. From the point of view of number of daughters per testing bull, Fewson & Niebel (1986) declared that increase in number of daughters per sire as ≥100 had large influence on increase of accuracy of estimated breeding values of functional traits, but had little impact on the accuracy of total merit and genetic gain in terms of monetary unit. Sørensen et al. (1999) observed that, on average, increase in daughter group size from 80 to 160 had no effect on total genetic response. However, composition of traits changed resulting in a decrease in the genetic response for milk production traits and an increase in genetic response for cost-reducing traits such as fertility, mastitis and health. Therefore, they suggested daughter group size of 160. Willam et al. (2002) reported that increasing number of daughters per sire up to 100 resulted in 1 to 5% increase in discounted profit compared to 60 daughters per sire. Differences in obtained results with abovementioned studies could be due to difference in (co)variance parameters, economic values and also population size and selection structure.

Scenario 2

Predicted genetic gain for each trait obtained from restricted selection indices are shown in Table 4 and Supplementary Table S2. In some cases, the aim is to keep the level of a trait (e.g. Mast) constant in order to cope with the decline in desirability due to selection for production traits. Economic values for Mast and Pro were selected using iteration method such that genetic response for these traits reached zero. In index 12 and in the case of daughter group size of 100, the genetic and economic responses of Pro were as 4.783 kg and 48.260 $, respectively (Table 3). In spite of negative economic value (−1.02 $) for Pro, there was a positive response for this trait due to high genetic correlation with Milk. The economic value of −5.459 $ was needed to fix genetic response for Pro at zero. By imposing restriction on Pro, responses to selection for Milk and Fat were reduced by 136.1 kg (72.1%) and 2.632 kg (84.63%), respectively (Table 4). Also, corresponding values for CI and DFS were shifted 3.925 d (118.26%) and 1.5 d (110.05%) in the desired direction, respectively. This is the only index with genetic trend for Mast which was due to positive genetic correlation between Pro and Mast. Although, aforementioned index led to considerable improvement in fertility traits and little improvement in udder health traits, but resulted in severe reduction in total economic response (12.14 $ or 25.16%). This can be interpreted as a high genetic correlation between Pro with Milk and Fat and also high heritability of these traits which caused high response to selection for these traits.

We needed to apply an economic value of −463 $ to maintain Mast constant at zero. Applying restriction on Mast, responses to selection for Milk and Fat were reduced by 37.92 kg (20.08%) and 0.772 kg (24.82%), respectively. However, correlated responses for CI and DFS were favorable shifted by 1.709 d (51.49%) and 0.459 d (33.68%), respectively (Table 4). In comparison to complete index 12, restriction on Mast did not reduce economic response because restriction was imposed on Pro (1.643 $ or 3.4%). This could be due to the fact that correlation of production traits with Mast was not as high as that of with Pro. On the other hand, reductions in response to selection for Milk and Fat due to restriction on Mast were counterbalanced partly through favorable response to selection in fertility traits and Pro. Similarly, in order to construct a sustainable breeding goal, Nielsen et al. (2005) established an index which included milk yield, mastitis resistance, conception rate and stillbirth. To increase animal welfare, they used restricted indices and observed that allocating non-market economic values to Mast, not only increased response to selection in resistance to mastitis but also improved conception rate due to positive genetic correlation between mastitis resistance and conception rate. Also, they reported that with allocation of non-market economic values, response to selection was only slightly reduced. The average economic gain of restricted indices was higher in daughter group size of 200 than that in daughter group size of 100 (as 5.149%).

Scenario 3

In this scenario, restriction was simultaneously imposed on two traits. Predicted genetic gains for each trait are shown in Table 4 and Supplementary Table S2. Economic values for CI and DFS and also for Pro and Mast were selected such that

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Table 3. Expected genetic and economic (in parentheses) gains for different traits in breeding goal using different indices (based on 100 progenies per sire)

Index no.	Milk	Protein	Fat	DFS	CI	Mast	SCS	TR
1	248.503 (49.701)	6.530 (−6.661)	4.347 (5.912)	1.084 (−2.168)	3.264 (−8.160)	0.022 (−1.76)	0.006 (−0.216)	36.648
2	246.430 (49.286)	6.512 (−6.642)	4.997 (6.796)	1.172 (−2.344)	3.640 (−9.100)	0.022 (−1.760)	0.003 (−0.108)	36.128
3	245.554 (49.111)	6.302 (−6.428)	5.041 (6.856)	1.153 (−2.306)	3.469 (−9.123)	0.022 (−1.760)	0.005 (−0.180)	36.170
4	218.111 (43.622)	5.491 (−5.601)	3.720 (5.059)	−0.648 (1.296)	−1.354 (3.385)	0.013 (−1.040)	−0.012 (0.432)	47.154
5	243.284 (48.657)	6.179 (−6.303)	4.860 (6.610)	0.588 (−1.176)	2.324 (−5.810)	0.021 (−1.680)	0.002 (−0.072)	40.226
6	198.480 (39.696)	4.927 (−5.026)	3.214 (4.371)	−1.222 (2.444)	−2.744 (6.860)	0.011 (−0.880)	−0.015 (0.540)	48.006
7	245.485 (49.097)	6.332 (−6.459)	5.046 (6.863)	1.111 (−2.222)	3.459 (−8.648)	0.021 (−1.680)	0.003 (-0.0108)	36.843
8	244.996 (48.999)	6.359 (−6.486)	5.116 (6.958)	1.101 (−2.202)	3.419 (−8.548)	0.022 (−1.760)	0.001 (−0.036)	36.925
9	244.595 (48.919)	6.383 (−6.511)	5.117 (6.959)	1.056 (−2.112)	3.214 (−8.050)	0.021 (−1.680)	−0.000 (0.017)	37.504
10	192.712 (38.542)	4.808 (−4.904)	3.088 (4.200)	−1.327 (2.654)	−3.116 (7.790)	0.009 (−0.720)	−0.017 (0.612)	48.174
11	194.890 (38.978)	4.908 (−5.006)	3.238 (4.404)	−1.261 (2.522)	−2.953 (7.383)	0.010 (−0.800)	−0.019 (0.684)	48.164
12	188.849 (37.770)	4.783 (−4.879)	3.110 (4.230)	−1.363 (2.726)	−3.319 (8.298)	0.008 (−0.640)	−0.021 (0.756)	48.260
13	211.840 (42.368)	5.525 (−5.636)	2.798 (3.805)	−0.801 (1.602)	−2.077 (5.193)	0.011 (−0.880)	−0.013 (0.468)	46.920
14	213.492 (42.698)	5.606 (−5.718)	2.960 (4.026)	−0.748 (1.496)	−1.942 (4.855)	0.012 (−0.960)	−0.015 (0.540)	46.937
15	208.266 (41.653)	5.506 (−5.616)	2.833 (3.853)	−0.848 (1.696)	−2.305 (5.763)	0.010 (−0.800)	−0.017 (0.612)	47.160

Milk, 305-d milk yield; Pro, 305-d protein yield; Fat, 305-d fat yield; DFS, days to first service; CI, calving interval; Mast, mastitis; SCS, somatic cell score; TR, total response.
Generation interval varied between 4.200 and 4.203 among indices.

Table 4. Expected genetic and economic (in parentheses) gains for different traits in breeding goal using different restricted indices (based on 100 progenies per sire)

Index no.	Milk	Protein	Fat	DFS	CI	Mast	SCS	TR
Pro restricted	52.791 (10.558)	0.000 (0.000)	0.478 (0.650)	−2.863 (5.726)	−7.244 (18.110)	−0.004 (0.320)	−0.021 (0.756)	36.120
Mast restricted	150.925 (30.185)	3.962 (−4.041)	2.338 (3.180)	−1.822 (3.644)	−5.028 (12.570)	0.000 (0.000)	−0.030 (1.080)	46.617
DFS & CI restricted	230.525 (46.105)	5.957 (−6.076)	4.348 (5.913)	0.000 (0.000)	0.000 (0.000)	0.015 (−1.200)	−0.012 (0.432)	45.174
Pro & Mast restricted	55.734 (11.147)	0.000 (0.000)	0.542 (0.737)	−2.827 (5.654)	−7.046 (17.615)	0.000 (0.000)	−0.019 (0.684)	35.837

Milk, 305-d milk yield; Pro, 305-d protein yield; Fat, 305-d fat yield; DFS, days to first service; CI, calving interval; Mast, mastitis; SCS, somatic cell score; TR, Total Response.
Generation interval varied between 4.196 and 4.201 among indices.

genetic trend for these traits reached zero. In order to fulfill the index, economic values of −1.46 $ and −0.081 $ for CI and DFS, and −5.6 $ and −20 $ for Pro and Mast were needed, respectively. Applying restriction on both CI and DFS increased genetic response for Milk (as 41.676 kg or 22.07%) and Fat (as 1.238 kg or 39.81%), compared with index 12. However, total economic response decreased by 6.39%.

In another index which imposed restriction on both Pro and Mast, severe reduction was observed in total economic response (12.423 $ or 25.74%) and in response to selection for Milk (133.1 kg or 70.49%) and Fat (2.568 kg or 82.57%). Obviously, this was due to high genetic correlation between Pro and other production traits. Generally, restriction on indices was associated with reduction in economic efficiency which varied from 3.4 to 25.74%. In an example presented by Cunningham et al. (1970), applying restriction on an index resulted in considerable reduction in efficiency. Therefore, they recommended that if this reduction is too high to pay, partial restrictions can be used.

Conclusion

By including reproductive traits in the index, considerable increase in economic gain was observed which indicates reproductive traits might play an important role in the profitability of dairy industry. Since Mast had a very low heritability, in spite of a favorable genetic correlation with reproductive traits, combining this trait with reproductive traits in an index did not result in considerable improvement in genetic gain. The results showed that the full index which included all production, reproduction and udder health traits resulted in the highest total genetic and economic gains. However, in case of unavailability of information such as genetic parameters and economic values for all traits and also simplicity rule and easiness for users, it can be recommended to use a simplified index which only included Milk, CI and SCS (due to higher number of records for somatic cell count with higher reliability compared with records of mastitis incidence in Iran) which reduced total economic gain only 2.74% relative to full index.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S0022029918000821

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References

Buttchereit N, Stamer E, Junge W and Thaller G (2011) Short communication: genetic relationships among daily energy balance, feed intake, body condition score, and fat to protein ratio of milk in dairy cows. *Journal of Dairy Science* **94**, 1586–1591.

Chegini A (2017) *Genetic and economic aspects of mastitis in Holstein cows of Iran*. PhD thesis, University of Guilan, Iran.

Christensen LG (1998) Possibilities for genetic improvement of disease resistance, functional traits and animal welfare. *Acta Agriculturae Scandinavica Section A–Animal Science* **29**, (Suppl.) 77–89.

Cunningham EP, Moen RA and Gjedrem T (1970) Restriction of selection indexes. *Biometrics* **26**, 67–74.

Dekkers JCM (2003) *Design and Economics of Animal Breeding Strategies*. Iowa, USA: Iowa State University.

Fewson D and Niebel E (1986). Berücksichtigung indirekter Merkmale in Zuchtplänen für Zweinutzungsrinder. *Züchtungskunde* **58**, 4–20.

Fuerst-Waltl B, Fuerst C, Obritzhauser W and Egger-Danner C (2016) Sustainable breeding objectives and possible selection response: finding the balance between economics and breeders' preferences. *Journal of Dairy Science* **99**, 1–14.

Ghiasi H, Nejati-Javaremi A, Pakdel A and Gonzalez-Recio O (2013) Selection strategies for fertility traits of Holstein cows in Iran. *Livestock Science* **152**, 11–15.

Gonzalez-Recio O, Alenda R, Chang Y, Weigel K and Gianola D (2006) Selection for female fertility using censored fertility traits and investigation of the relationship with milk production. *Journal of Dairy Science* **89**, 4438–4444.

Hazel LN (1943) The genetic basis for constructing selection indexes. *Genetics* **28**, 476–490.

Kempthorne O and Nordskog AW (1959) Restricted selection indexes. *Biometrics* **15**, 10–19.

Lassen J, Sørensen MK, Madsen P and Ducrocq V (2007) A stochastic simulation study on using different models for prediction of breeding values while changing the breeding goal. *Animal: An International Journal of Animal Bioscience* **1**, 631–636.

Lindhe B and Philipsson J (1998) Genetic correlations between production with disease resistance and fertility in dairy cattle and consequences for total merit selection. *Acta Agriculturae Scandinavica Section A–Animal Sience* **48**, 216–221.

Mathworks (2009a) *MATLAB – The Language of Technical Computing – Getting Started with MATLAB Version 7.8.0*. Natick, MA: The MathWorks.

Miglior F, Muir BL and Van Doormaal BJ (2005) Selection indices in Holstein cattle of various countries. *Journal of Dairy Science* **88**, 1255–1263.

Nielsen HM, Christensen LG and Groen AF (2005) Derivation of sustainable breeding goals for dairy cattle using selection index theory. *Journal of Dairy Science* **88**, 1882–1890.

Rutten MJ and Bijma P (2001) *SelAction Manual*. Wageningen, The Netherlands: University of Wageningen.

Sadeghi-Sefidmazgi A, Moradi-Shahrbabak M, Nejati-Javaremi A and Shadparvar A (2009) Estimation of economic values in three breeding perspectives for longevity and milk production traits in Holstein dairy cattle in Iran. *Italian Journal of Animal Science* **8**, 359–375.

Sadeghi-Sefidmazgi A, Moradi-Shahrbabak M, Nejati-Javaremi A, Miraei-Ashtiani SR and Amer PA (2011) Estimation of economic values and financial losses associated with clinical mastitis and somatic cell score in Holstein dairy cattle. *Animal: An International Journal of Animal Bioscience* **5**, 33–42.

Sadeghi-Sefidmazgi A, Moradi-Shahrbabak M, Nejati-Javaremi A, Miraei-Ashtiani SR and Amer PA (2012) Breeding objectives for Holstein dairy cattle in Iran. *Journal of Dairy Science* **95**, 3406–3418.

Schaeffer L (2014) Making covariance matrices positive definite. http://www.aps.uoguelph.ca/~Irs/ELARES/PDforce.pdf.

Sneddon NW, Lopez-Villalobos N, Davis SR, Hickson RE, Shalloo L, Garrick DJ and Geary U (2016) Responses in lactose yield, lactose percentage and protein-to-protein plus-lactose ratio from index selection in New Zealand dairy cattle. *New Zealand Journal of Agricultural Research* **59**, 90–105.

Sölkner J, Miesenberger J, Willam A, Fürst Ch and Baumung R (2000) Total merit indices in dual purpose cattle. *Archiv Tierzucht* **43**, 597–608.

Sørensen MK, Berg P, Jensen J and Christensen LG (1999) Stochastic simulation of breeding schemes for total merit in dairy cattle. GIFT seminar on genetic improvement of functional traits in cattle, Wageningen, The Netherlands, 7–9 November. *Interbull Bulletin* **23**, 183–192.

Willam A, Egger-Danner C, Sölkner J and Gierzinger E (2002) Optimization of progeny testing schemes when functional traits play an important role in the total merit index. *Livestock Production Science* **77**, 217–225.

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