IJAS Iranian Journal of Applied Animal Science

Simple and Constrained Selection Indices with and without Calving Interval Included in Selection Goal Function for Holstein Cows of Iran

Research Article

E. Darang[1], A.A. Shadparvar[2*] and M. Golshani[1]

[1] Agriculture Jihad Organization of Guilan, Guilan, Rasht, Iran
[2] Department of Animal Science, Faculty of Agricultural Science, University of Guilan, Rasht, Iran

Received on: 26 Dec 2018
Revised on: 7 Apr 2019
Accepted on: 15 Apr 2019
Online Published on: Sep 2020

*Correspondence E-mail: shad@guilan.ac.ir

Online version is available on: www.ijas.ir

ABSTRACT

Two selection goals of inclusion or exclusion of calving interval (CI) in the selection goal function for Holstein cows in Iran, besides milk yield, milk fat percentage, and milk protein percentage, were studied. Four selection indices were composed of using the information on production traits, CI and / or days from calving to first insemination (DFI). The results of the predicted genetic growth in selection goals showed that the index composed of all production and reproduction traits generated the greatest genetic growth. Although CI had a negative coefficient in the selection goal, it is genetic mean increased in any case. However, the magnitude of this undesirable increase was lower in the CI included selection goal. This implies that the inclusion of CI in the selection goal is necessary to control the undesirable growth of this trait. The comparison of indices in this goal reflected that the inclusion of CI along with the production traits resulted in a smaller undesirable change in this trait. Constraining the genetic change in CI in the selection goal impaired the selection efficiency. So, this constraint is not recommended for breeding programs.

KEY WORDS calving interval, constrained selection index, genetic growth, Holstein.

INTRODUCTION

In genetic improvement programs, it is vital to make prudent decisions on the selection of individual animals that can transfer the highest bioeconomic value to the next generations. So far, the selection index method has been proven to be the best among all multi-trait selection methods (Sölkner and Fuerst, 2002). Recent studies have revealed extensive use of the selection index to dairy cattle herds throughout the world (Cole and VanRaden, 2018). In Iran, Joezi Shekalgoorabi and Shadparvar (2009) used the estimation of the economic coefficient of milk yield, fat percentage, and herd life as the goal traits of breeding programs and their genetic and phenotypic parameters to present an optimal selection index for dairy cattle. If a genetic improvement program targets herd profitability through increasing the genetic capacity of production and reproduction yield of the animals, it should be adjusted with a selection index in that the breeding value of the animals for major economic traits has been embedded (Pourtaher *et al.* 2016). Reproductive traits play an important role in bolstering the income of the dairy cattle industry, so livestock breeding programs give special attention to them (Gholizadeh *et al.* 2013).

In recent years, genetic selection programs have led to significant advances in milk production, but in contrast, the fertility rate has exhibited a declining trend (Liu *et al.* 2007). Various studies have documented undesirable genetic and phenotypic correlations between production and reproduction traits (Evans *et al.* 2006; McCarthy *et al.* 2007; Liu *et al.* 2007). Since reproduction problems, such as infertility, are the main reason for the culling of animals in herds (Mohammadi and Sedighi, 2009), it is imperative to include these traits along with the production traits in establishing a selection index so that the genetic growth in milk yield trait is increased and at the same time, the genetic recession of reproduction traits is avoided. Since no study in Iran has ever addressed the inclusion of reproduction traits in dairy cattle selection index, the present study aims to include these traits in the selection index equation along with milk yield traits.

MATERIALS AND METHODS

Data

Economic coefficients

The present study regarded the traits of milk yield, fat percentage, protein percentage, and calving interval (CI) as the main economic traits in breeding programs of dairy cows in Iran. The economic coefficients of these traits were considered to be 3223, 127.644, -504.774, and -73.814, respectively (Athari Mortazavi, 2010).

Genetic and phenotypic parameters

We used the phenotypic and genetic coefficients and heritability estimated by Togyani (2007) for milk yield (Milk), fat percentage (Fat %), protein percentage (Pro %), calving interval (CI), and days from calving to first insemination (DFI). These parameters are summarized in Table 1.

Goal function and selection indices

Two selection goal functions to accomplish the genetic growth of goal selection were formed as below under the condition that the economically important traits were changed for animal farmers:

$$H_1 = v_1\,A_{(Milk)} + v_2\,A_{(Fat\,\%)} + v_3\,A_{(Pro\,\%)} + v_4\,A_{(CI)}$$
$$H_2 = v_1\,A_{(Milk)} + v_2\,A_{(Fat\,\%)} + v_3\,A_{(Pro\,\%)}$$

For each of these goal functions, four selection indices were defined as below:

1) *Index 1* in which milk yield, milk fat percentage, and protein percentage were included

2) *Index 2* in which milk yield, milk fat percentage, protein percentage, and calving interval were included

3) *Index 3* in which milk yield, milk fat percentage, protein percentage, calving interval, and days from calving to first insemination were included

4) *Index 4* in which milk yield, milk fat percentage, protein percentage, and days from calving to first insemination were included

The matrices that were established for these indices included the phenotypic variance-covariance matrix between the traits that were included in the selection index equation (matrix P), the genetic variance-covariance matrix between the traits that were included in the selection index equation and selection goal (matrix G˚), and the genetic variance-covariance matrix between the traits that were included in the selection goal (matrix C). The coefficients of selection index, genetic growth in selection goal (considering selection intensity 1), selection accuracy, and genetic growth in each individual selection goal were calculated. Since we need the phenotypic and genetic variances and covariance in order to form matrices, the genetic variance of the traits was first calculated using phenotypic variances and heritabilities as below:

$$\sigma^2_{gi} = h_i^2 \sigma^2_{pi_i} \quad (1\text{-}2)$$

Where:
i: represents the ith trait.

Also, the genetic and phenotypic covariances between different traits were calculated by:

$$Cov_{g_{x,y}} = r_{g_{x,y}} \sqrt{\sigma^2_{g_x} \sigma^2_{g_y}} \quad (2\text{-}2)$$
$$Cov_{p_{x,y}} = r_{p_{x,y}} \sqrt{\sigma^2_{p_x} \sigma^2_{p_y}} \quad (3\text{-}2)$$

All calculations were performed in the Matlab 7 software package. The results of different matrices in each selection goal were compared, and the index that gave the highest genetic growth in each selection goal was regarded as the optimal index for the respective goal.

Constraining genetic growth of calving interval trait

CI is a trait whose increase in breeding programs is perceived to be undesirable as its increase means lower genetic growth and the loss of profit. One way to control the fluctuations of this trait is to use constrained selection indices. In these indices, the genetic growth is equal to zero despite the genetic correlation of the certain trait with other traits. In other words, in spite of the selection for other traits, no change happens in the genetic growth of the constrained trait.

To apply the constraint here, we considered the genetic growth of CI to be zero in selection goal 2 in which calving interval was excluded. Then, the selection indices in which this trait was included (indices 2 and 3) were formed again for this goal, and the genetic growth and the variance of the index for selection goal 2, as well as the genetic growth of each individual trait, were studied again under the constrained conditions.

Table 1 Genetic and phenotypic correlations of the studied traits (figures on the diagonal show heritability, those above diagonal show genetic correlation, and those below the diagonal show phenotypic correlation)

Trait	M	F %	P %	CI	DFI	σ^2_p
Milk yield (M)	**0.26**	-0.61	-0.505	0.593	0.022	1119213
Fat percentage (F %)	-0.47	**0.31**	0.16	-0.19	0.02	0.1366
Protein percentage (P %)	-0.241	0.1385	**0.228**	-0.002	-0.003	0.0347
Calving interval (CI)	0-084	-0.016	-0.002	**0.0657**	0.0005	3909.698
Days from calving to first insemination (DFI)	0.05	0.011	-0.004	0.0001	**0.04**	2921.379

σ^2_p: shows the phenotypic variance of the studied traits.

Finally, the results were compared with the conditions in which there were no constraints on the genetic growth of CI. The matrix form of the equation used to constrain the genetic growth of zero in CI was as below:

$$\begin{bmatrix} P & G_1 \\ G_1 & 0 \end{bmatrix}\begin{bmatrix} b \\ \lambda \end{bmatrix}=\begin{bmatrix} Gv \\ 0 \end{bmatrix}$$

P: phenotypic variance-covariance matrix of index traits.
G_1: denotes the variance-covariance matrix of index traits and CI.
v: economic coefficient of selection goal traits.
λ: extra unknown that is added to the vector of weight responses of the index.

After the estimation of index coefficient, the genetic growth in each trait and the genetic growth of selection goals were calculated by the new coefficient of the index.

RESULTS AND DISCUSSION

Selection goal 1

The coefficient of the index (b) that is presented in Table 2 was negative for the traits of milk, fat percentage, milk protein percentage, calving interval (CI), and days from calving to first insemination (DFI). This negative coefficient can be attributed to the strong negative genetic correlation of fat percentage and milk yield, the strong negative economic coefficient of CI, and the weak correlation of DFI with the traits included in goal selection.

Table 3 presents the variance of selection indices, genetic growth in selection goal, and selection accuracy using a personal record. The variations of index variance and genetic growth exhibited similar trends because of the direct relationship of index variance with genetic growth of selection goal.

The lowest genetic growth was obtained from index 1 (including the least number of traits) and the highest was obtained from the most developed index (index 3) in which the most number of traits were included. The inclusion of CI in the index equation (indices 2 and 3) influenced the genetic growth derived from selection goal equation strongly so that when this trait was excluded from the index function (indices 1 and 4), the genetic growth derived from the selection goal equation was the lowest. This demonstrates the significance of CI inclusion in order to effectively select for the improvement of genetic growth. CI inclusion in the index equation enhanced the genetic growth of the selection goal because of its negative economic coefficient. When more traits are considered as the criteria for the comparison of individual animals, the variance among the individual animals is unveiled to a greater extent. This is manifested as an increase in index variance and consequently, an increase in genetic growth due to the selection. This is consistent with Joezi Shekalgoorabi (2004). Similarly, Sivanadian and Smith (1997) showed that adding further traits to index selection would enhance genetic growth in the case of the consistency of matrices in all cases. The comparison of genetic growth derived from the index in which CI was replaced with DFI showed a further decline of genetic growth (index 4 *vs*. index 2). This can be attributed to low heritability of DFI and its weaker genetic correlation with the selection goal traits. We estimated the genetic growth as per one single generation (not the genetic growth over time) in which generation interval was not involved. When DFI is used instead of CI, generation interval is shortened and this, in turn, improves genetic growth over time. So, our results cannot be generalized to genetic growth over time and this requires further research.

The index selection accuracy of selection goal 1 did not show significant differences to one another (Table 3). Selection accuracy reflects the correlation between an index and a selection goal. Since the variance of the selection goal is constant for different indices, the difference in selection accuracy in different selection indices depends on the genetic correlation of the traits included in that index and the selection goal, as well as on the phenotypic correlation between the traits included in the index equation. The selection accuracy in index 4 (including milk yield, fat percentage, protein percentage, and DFI) was equal to that of index 1 (including milk yield and fat percentage) owing to the low genetic correlation between DFI and the traits of selection goal and low phenotypic correlation between this trait and the index traits.

Table 2 Coefficients of different selection indices of the selection goal 1 including milk yield, fat percentage, protein percentage, and calving interval

Selection index	M	F %	P %	CI	DFI
1	311.91	-726461.05	-1618093.91	-	-
2	318.89	-720693.76	-1610896.44	-1154.19	-
3	319.42	-719781.16	-1610590.62	-1154.84	-141.18
4	312.41	-75597.21	-1678807.24	-	-134.12

M: milk yield; F %: fat percentage; P %: protein percentage; CI: calving interval and DFI: days from calving to first insemination.
$I_1 = b_1M + b_2F\% + b_3P\%$
$I_2 = b_1M + b_2F\% + b_3P\% + b_4CI\%$
$I_3 = b_1M + b_2F\% + b_3P\% + b_4CI\% + b_5DFI$
$I_4 = b_1M + b_2F\% + b_3P\% + b_4DFI$

Table 3 Selection variance and accuracy using a personal record for four selection indices and the genetic growth of the selection goal 2 including milk yield, fat percentage, protein percentage, and calving interval

Selection index[1]	Selection index variance	Genetic growth in selection goal[2]	Selection accuracy
1	42546869	6522.796	0.46
2	43063490	6562.278	0.47
3	43069289	6562.720	0.47
4	42552102	6523.197	0.46

[1] Index variance values are divided by 10^4 and genetic growth values are divided by 10^2.
[2] Geneticl growth was considered with selection intensity 1.
$I_1 = b_1M + b_2F\% + b_3P\%$
$I_2 = b_1M + b_2F\% + b_3P\% + b_4CI\%$
$I_3 = b_1M + b_2F\% + b_3P\% + b_4CI\% + b_5DFI$
$I_4 = b_1M + b_2F\% + b_3P\% + b_4DFI$

The genetic growth of all traits included in selection goal 1 is presented in Table 4. CI was escalated in all indices, but this is an unfavorable change that is associated with the strong positive genetic correlation between CI and milk yield. This finding supports Pryce *et al*. (2002) and Pryce *et al*. (2004) who have stated that selection for high milk yield results in undesirable genetic growth of fertility traits. However, the magnitude of this undesirable increase was lower in indices in that CI was a constituent trait (i.e. indices #2 and #3) than in other indices. The inclusion of DFI in the selection index could not inhibit the undesirable genetic growth in CI. This is evident in the comparison of genetic growth of CI in index 1 with that in index 4. This may be related to the weak genetic correlation between CI and DFI. The fact that the coefficient of the index was negative for CI implied that a negative weight should be assigned to this trait in the function of the selection index and this would reduce the genetic growth of the traits as compared to the state in which the trait was excluded. The strong positive genetic correlation between CI and milk yield in the selection goal, which had high positive economic coefficient too, did not allow the genetic growth of this trait to be negative.

The fat percentage of milk showed almost equal and negative genetic growth in different indices. Selection for milk yield decreased fat percentage (Nazari *et al*. 2007; Kheirabadi and Alijani, 2013).

The results of different indices reveal that index 3 is an optimal index for the selection goal because both the highest growth in the selection goal and the relatively lowest undesirable change happens in CI.

Selection goal 2

The coefficients of four different selection indices for the selection goal 2 are presented in Table 5 for the traits of milk yield, fat percentage, and protein percentage. As was explained for the selection goal 1, the coefficients were negative for the traits of fat percentage, protein percentage, and DFI.

Unlike what was found for the selection goal 1, the coefficient *b* was positive for CI. Since CI was excluded from the selection goal 2 as a trait with a high negative economic coefficient and it had a strong positive genetic correlation with milk yield that carried the highest economic coefficient in the selection goal, the index coefficient of this trait became positive.

Table 6 shows the variance of selection index and genetic growth in selection goal and the selection accuracy in goal 2. The selection accuracy was higher for the three-trait selection goal indices (selection goal 2) than for the four-trait selection goal (1). This is in agreement with Joezi Shekalgoorabi and Shadparvar (2009) who stated that the increase in the variance of selection goal in the selection with more traits impaired the accuracy of the selection. The highest selection accuracy in the selection goal 2 was 0.55 obtained from indices 2 and 3, and the lowest was 0.54 related to the indices 1 and 4.

The inclusion of either CI or DFI in the index increased the genetic growth of the selection goal. Showing the highest index variance of the highest genetic growth, the selection index 3 was considered the optimal index. Also, index 1 that encompassed the fewest traits exhibited the lowest index variance and genetic growth.

Table 4 Genetic growth of the traits included in the selection goal 1

Selection index	M	F %	P %	CI
1	274.67	-0.868	-0.0345	3.16
2	266.24	-0.855	-0.344	2.73
3	266.32	-0.855	-0.344	2.74
4	274.75	-0.868	-0.0345	3.16

M: milk yield; F %: fat percentage; P %: protein percentage and CI: calving interval.
$I_1 = b_1M + b_2F\% + b_3P\%$
$I_2 = b_1M + b_2F\% + b_3P\% + b_4CI\%$
$I_3 = b_1M + b_2F\% + b_3P\% + b_4CI\% + b_5DFI$
$I_4 = b_1M + b_2F\% + b_3P\% + b_4DFI$

Table 5 Coefficients of four selection indices of the selection goal 2 (milk yield, fat percentage, protein percentage)

Selection index	M	F %	P %	CI	DFI
1	693.52	-585005.08	-1140720.68	-	-
2	674.13	-601017.45	-1160703..82	3204.51	-
3	675.97	-597841.14	-1159639.41	3202.25	-491.39
4	695.41	-581713.82	-1139628.46	-	-510.99

M: milk yield; F %: fat percentage; P %: protein percentage; CI: calving interval and DFI: days from calving to first insemination.
$I_1 = b_1M + b_2F\% + b_3P\%$
$I_2 = b_1M + b_2F\% + b_3P\% + b_4CI\%$
$I_3 = b_1M + b_2F\% + b_3P\% + b_4CI\% + b_5DFI$
$I_4 = b_1M + b_2F\% + b_3P\% + b_4DFI$

Table 6 The variance of six selection indices and genetic growth of the selection goal 2 (milk yield, fat percentage, protein percentage)

Selection index[1]	Selection index variance	Genetic growth in selection goal[2]	Selection accuracy
1	86720001	9312.3574	0.54
2	90702353	9523.7783	0.55
3	90772605	9527.4658	0.55
4	86795971	9316.4355	0.54

[1] Index variance values are divided by 10^4 and genetic growth values are divided by 10^2.
[2] Geneticl growth was considered with selection intensity 1.
$I_1 = b_1M + b_2F\% + b_3P\%$
$I_2 = b_1M + b_2F\% + b_3P\% + b_4CI\%$
$I_3 = b_1M + b_2F\% + b_3P\% + b_4CI\% + b_5DFI$
$I_4 = b_1M + b_2F\% + b_3P\% + b_4DFI$

Further research is required to answer the question as to whether this difference in genetic growth between two indices offsets the extra costs of recording more traits for the optimal selection index.

The genetic growth of each individual trait in the selection goal 2 is presented in Table 7. The inclusion of CI in the selection index improved the genetic growth of milk yield because of the absence of CI in the selection goal and its strong positive genetic correlation with milk yield.

Correlated genetic growth of CI in selection goal

Table 8 shows the correlated genetic growth of CI in the selection goal 2. In indices in which this trait was included, its correlated genetic growth was increased because of its positive genetic correlation with milk yield. The replacement of CI with DFI demonstrated that the correlated genetic growth of CI in these indices did not differ significantly from the conditions in which none of the reproductive traits was present. This can be attributed to the weak genetic correlation between DFI and the traits of the selected goal.

These results were similar to conditions in which the trait was included in the selection goal (selection goal 1).

The comparison of the genetic growth of CI in the selection goal 1 (including the traits of milk yield, fat percentage, protein percentage, and CI; Table 4) and its correlated genetic growth in the selection goal 2 (including the traits of milk yield, fat percentage, and protein percentage; Table 8) revealed that this trait had more undesirable genetic growth when it was absent in the selection goal (selection goal 2). This is because of the impact of the high negative economic coefficient of CI in the selection goal 1 on the decline of the undesirable genetic growth of this trait.

Results of applying the constraint on calving interval

Tables 9 and 10 present the results of variance and genetic growth of the selection goal 2 and the genetic growth of individual traits of this goal for constrained indices in which CI had been included, respectively. The decline of index variance reduced the genetic growth of the selection goal in constrained indices. Index 4 exhibited higher genetic growth than index 2.

Table 7 Genetic growth of traits in the selection goal 2 including milk yield, fat percentage, and protein percentage

Selection index	M	F %	P %
1	288.93	-0.0806	-0.0298
2	295.49	-0.0803	-0.0287
3	295.61	-0.0803	-0.0287
4	289.06	-0.0806	-0.0296

M: milk yield; F %: fat percentage and P %: protein percentage.
$I_1 = b_1M + b_2F\% + b_3P\%$
$I_2 = b_1M + b_2F\% + b_3P\% + b_4CI\%$
$I_3 = b_1M + b_2F\% + b_3P\% + b_4CI\% + b_5DFI$
$I_4 = b_1M + b_2F\% + b_3P\% + b_4DFI$

Table 8 Correlated genetic growth of calving interval in the selection goal 2 including milk yield (M), fat percentage (F %), and protein percentage (P %)

Selection index	Calving interval
1	4.21
2	4.89
3	4.89
4	4.22

$I_1 = b_1M + b_2F\% + b_3P\%$
$I_2 = b_1M + b_2F\% + b_3P\% + b_4CI\%$
$I_3 = b_1M + b_2F\% + b_3P\% + b_4CI\% + b_5DFI$
$I_4 = b_1M + b_2F\% + b_3P\% + b_4DFI$

Table 9 Variance and genetic growth of selection indices encompassing calving interval in the selection goal 2 after applying the constraint

Selection index[1]	Selection index variance	Genetic growth in selection goal	Selection accuracy
2	34764305419	5896.1263	0.34
3	34766082451	5896.277	0.34

[1] Index variance values are divided by 10^4 and genetic growth values are divided by 10^2.
$I_2 = b_1M + b_2F\% + b_3P\% + b_4CI\%$
$I_3 = b_1M + b_2F\% + b_3P\% + b_4CI\% + b_5DFI$

Table 10 Genetic growth of traits in the selection goal 2 after applying constraint 0 for the trait of calving interval in the selection goal 2

Selection index	M	F %	P %
2	147.8	-0.0869	-0.0116
3	147.8	-0.0869	-0.0116

M: milk yield; F %: fat percentage and P %: protein percentage.
$I_2 = b_1M + b_2F\% + b_3P\% + b_4CI\%$
$I_3 = b_1M + b_2F\% + b_3P\% + b_4CI\% + b_5DFI$

The genetic growth of milk yield also showed a descending trend as compared to its counterpart when CI was not constrained (Table 10). This is related to the strong positive genetic correlation between milk yield and CI.

CONCLUSION

The presence of CI in the selection goal plays an essential role in controlling the undesirable improvement of this trait. In the CI-included goal, the replacement of CI with CFI in the index intensified the undesirable change in this trait. Applying restriction on the genetic change in CI resulted in less selection efficiency and is not recommended in breeding schemes.

REFERENCES

Athari Mortazavi B. (2010). Comparison of economic values of milk yield and herd life traits of Holstein, hybrid and local cows in Guilan province. MS Thesis. Guilan Univ., Rasht, Iran.

Cole J.B. and VanRaden P.M. (2018). Symposium review: Possibilities in an age of genomics: The future of selection indices. *J. Dairy Sci*. **101(4),** 3686-3701.

Evans R.D., Buckley P. and Berry F. (2006). Trends in milk productions, calving rate and survival of cows in 14 Irish dairy herds as results of introgression of Holstein Friesian genes. *J. Anim. Sci*. **82,** 423-434.

Gholizadeh S., Ansari Mohayayi S., Riasi A. and Rokouei M. (2013). Estimation of inbreeding coefficient and its effect on some reproductive traits of daily herds in Isfahan province. *Iranian J. Anim. Sci. Res.* **5(3),** 251-256.

Joezi Shekalgoorabi S. (2004). Establishment of an optimal selection index for Holstein cows in Iran. MS Thesis. Guilan Univ., Rasht, Iran.

Joezi Shekalgoorabi S. and Shadparvar A. (2009). The effects of culling herd life from selection goal in Iranian Holstein cows. *Iranian J. Anim. Sci.* **40(1),** 13-20.

Kheirabadi K. and Alijani S. (2013). Effect of somatic cell counts on the production traits and estimation of genetic parameters for milk yield traits of Holstein cows. *Anim. Prod. Res.* **2(1),** 65-76.

Liu Z., Jaitner J., Pasman E., Resing S., Reinhardt F. and Reents R. (2007). Genetic evaluation of fertility traits of dairy cattle using a multiple trait model. *Interbull Bull*. **37,** 134-139.

McCarthy S., Horan B., Dillon P.O., Connor P., Rath M. and Shalloo L. (2007). Economic comparison of divergent. *J. Dairy Sci*. **90,** 1493-1505.

Mohammadi G.R. and Sedighi A. (2009). Reasons for culling of Holstein dairy cows in Neishaboor area in northeastern Iran. *Iranian J. Vet. Res.* **28,** 278-282.

Nazari M., Beigi Nasiri M. and Fayyazi J. (2007). Assessment of genetic and phenotypic capabilities of milk yield, fat, and fat percentage of Najdi dairy cows using single and two-trait animal model. *Iranian Vet. J.* **3(4),** 73-80.

Pourtaher S., Ra'fat S., Moghaddam G. and Shoja J. (2016). Estimation of genetic parameters for production traits and some reproduction disorders of dairy cows in one of the East Azerbaijan herds. *J. Anim. Sci. Res.* **25(4),** 1-9.

Pryce J.E., Coffey M.P., Brotherstone S.H. and Woolliams J.A. (2002). Genetic relationship between calving interval, body condition score conditional on milk yield. *J. Dairy Sci*. **85,** 1590-1595.

Pryce J.E., Royal M.D., Garnworthy P.C. and Mao I.L. (2004). Fertility in the high producing dairy cow. *Lives. Prod. Sci.* **86,** 125-135.

Sivanadian B. and Smith C. (1997). The effect of adding further traits in index selection. *J. Anim. Sci.* **75,** 2016-2023.

Sölkner J. and Fuerst C. (2002). Breeding for functional traits in high yielding dairy cow. Pp. 23-29 in Proc. 7th World Congr. Genet. Appl. Livest. Prod., Montpellier, France.

Togyani S. (2007). Estimation of genetic parameters of production, reproduction and type traits in Holstein cows of Iran MS Thesis. Guilan Univ., Rasht, Iran.