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Genetic and Economic Optimization of a Progeny Testing Program Regarding the Effect of Inbreeding in Test Scheme

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Abstract: The effect of inbreeding on the optimum combination of progeny group size and test capacity for progeny testing of young bull was explored in term of genetic improvement and economic efficiency of selection scheme. The impact of inbreeding on decreasing genetic variation was considered in the estimation of genetic improvement. Inbreeding reduced the genetic improvement and economic efficiency of selection scheme by approximately 4%. However it had slight impact on optimum combination of progeny group size and test capacity of test scheme. The optimum value of progeny group size and test capacity for maximum genetic improvement was 57 and 0.3, respectively. However for obtaining the maximum economic efficiency this combination changed to 142 and 0.1. In different test capacities, reaching to the greatest economic efficiency always led to sampling a much smaller number of young bulls comparing to their corresponding value for reaching to the maximum genetic improvement. Schemes for controlling inbreeding could not influence the optimum combination of test capacity and progeny group size unless number of dams to breed future sires change considerably.

Key words: Progeny test · Young bull · Inbreeding · Genetic improvement · Economic efficiency

INTRODUCTION

Dairy production in Iran, with approximately a million Holstein cow on commercial dairy farms, provides one of the main incomes in agricultural sector on this country [1]. In spite of being numerically a large population, inbreeding in Holstein has become a concern in the recent years. Inbreeding is basically influenced by the ratio of males to females, reproductive ability, population size, mating system and selection on few positively correlated traits [2-4]. The main consequences of inbreeding are inbreeding depression, more prevalence of undesirable recessive disorders and loss of genetic improvement as a result of loss of genetic variation [3]. In addition to lose of genetic superiority, annually a considerable amount of money invested in animal breeding units, is lost due to the effect of inbreeding [5, 6]. Choosing more sire and dams, not only leads to lower rate of inbreeding, but also decrease the selection intensity which would be resulted in less genetic improvement and economic efficiency of selection program [7]. Hence the optimum selection strategy could be a scheme with the highest amount of genetic improvement or economic efficiency and the lowest possible inbreeding.

In spite of the international competitive market of semen sale, there is no competitive market for the produced semen inside Iran. And yet the objective of the AI firm in Iran is to improve economic efficiency of dairy production by providing genetically superior semen at low price to producers than to develop genetically superior bulls for expanding the global market share. Progeny testing of sampled young bulls is yet the main strategy for producing marketable semen in Iran. Several factors, like number of daughters per sampled young bulls (progeny group size) and test capacity (the percent of recorded cow population bred to young bulls) have noticeable effect on the rate of genetic superiority and economic efficiency of selection program [8]. On the other hand the most important factor affecting the cost of progeny testing scheme is associated with the number of sampled young bulls [9].

Optimization of progeny testing program for the number of sampled young bulls and the extent of progeny group size has been studied extensively since 1960s and

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1970s with regard to the rate of genetic improvement and economic efficiency [9]. However, the optimum progeny testing scheme is not the same in different countries even if they have had similar selection goals [10]. Joezy-shekalgorabi *et al*. (2010) investigated the optimum selection strategy of Iranian Holstein from genetic and economic point of view [8 and 11]. However they did not consider the effect of inbreeding in choosing the optimum scheme. Artificial insemination and selection of few sires which have enormous impact on the breed will inevitably increase the rate of inbreeding. The objective of the current study was to find the optimum selection scheme from genetic and economic point of view with regard to the best possible combination of progeny group size and test capacity. The impact of inbreeding on genetic variation and therefore on genetic improvement of test scheme is regarded in the model.

MATERIALS AND METHODS

A deterministic model described fully in Joezy-shekalgorabi *et al*. (2010) was utilized for prediction of genetic improvement program in different selection pathways in Iranian Holstein [8]. Milk production was considered as selection goal; as this trait, similar to most developing countries, is the most important criteria of selection in Iran. Rate of inbreeding was computed as follow [12]:

$$\Delta F = \frac{4n_{SS}n_{DS}}{n_{SS} + n_{DS}}$$

Where n_{SS} refers to the number of selected SS (Sires to bred future Sire) and n_{DS} refers to number of selected DS (Dams to bred future Sires). The other two pathways (i.e. DS (Dams to bred future Sires) and DD (Dams to bred future Dams) were ignored due to their negligible effect on increasing the inbreeding coefficient. Genetic improvement was estimated by considering the effect of inbreeding on decreasing genetic variance [13]:

$$\sigma^2_{G_c} = (1 - F_t)\sigma^2_G$$

Where $\sigma^2_{G_c}$ and σ^2_G are genetic variance after and before implementing selection scheme, respectively. Also F_t refers to the inbreeding induced by selection in t^{th} round of selection. However for the first round of selection ΔF could be substituted in the previous equation. Hence, genetic improvement, considering the effect of inbreeding in the first round of selection could be estimated as below [13]:

Table 1: Selected proportion in different selection pathways*

Path	Proportion Selected
Sire of future Sires (SS)	$p_{SS} = \frac{nI_n e rr_{SS}}{Pd rr_f f_{ps}}$
Sire of future Dams (SD)	$p_{SD} = \frac{nI_n(1-P)rr_{SD}}{t \Pr rr_f d f_{ps}}$
Dam of future Sires (DS)	$p_{DS} = \frac{\Pr rr_f j}{n f_{ps} e o}$
Dam of future Dams (DD)	$p_{DD} = \frac{rr_f}{w}$

* t: percent of cows on milk recording (t=0.33), P: percent of cows bred to young bull semen (test capacity) (P=0.2), n: progeny group size (n=100), In: number of insemination per pregnancy (In=2.2), d: dose of semen used by each progeny tested bulls (d=18000), e: fraction of cows suitable for selection as dam of sons (elite dams) (e=0.3), j: number of needed elite pregnancies to obtain a young male (j=6.1), o: fraction of young bulls suitable for progeny testing (o=1), rr_f: cow replacement rate (rr_f=0.2), rr_{SS}: replacement rate of sire of sons (r_{SS}=0.25), rr_{SD}: replacement of sire of daughters (rr_{SD}=0.25), w: live daughters per dam of daughters (w=0.4), f_{ps}: fraction of young bulls pre-selected (f_{ps}=1).

$$\Delta G_c = \Delta G\sqrt{1 - \Delta F}$$

Where ΔG_c and ΔF represent genetic improvement after and before including inbreeding in the model. ΔG was computed as follow [8]:

$$\Delta G = \Delta G_{SS} + \Delta G_{SD}(1 - P) + \Delta G_{DS} + \Delta G_{DD}$$

Where subscripts *SS*, *SD*, *DS* and *DD* refer to different selection pathways and *P* is test capacity. Genetic improvement in different selection pathways was calculated in the unit of genetic standard deviation by multiplying selection accuracy and selection intensity related to that pathway. Accuracy of selection was predicted according to an individual record in dam pathways (DS and DD) and utilizing progeny evaluation in sire pathways (SS and SD). Selection intensity was predicted by truncation selection procedure and using selected proportion in different pathways implementing equations in table 1 [8].

Genetic improvement was obtained for different combination of progeny group size and test capacity with regard to the effect of inbreeding on genetic variation.

Cost benefit ratio (ratio of discounted return to discounted cost) was the base for comparing different selection strategies in term of economic efficiency.

Table 2: Costs and returns of a conventional progeny testing program in Iran

Economic parameters	Value ($)
Disease test per young bull	100
Feeding and maintenance per young bull in quarantine	100
Purchasing animals that pass quarantine (per young bull)	3000
Sperm collection per young bull	0.5
Sperm insemination per cow	0.5
Feeding per young bull per year in waiting period	1800
Maintenance per young bull	8400
Recording and evaluation of a daughter per young bull	10
Sperm collection and processing per dose per proved sire	0.7
Average price of culled test bulls or discarded proved sire	2100
Milk economic value	0.983

Returns were divided into two parts: returns from genetic improvement and returns from selling culled proven sires or young unproved bulls. Returns from genetic improvement were obtained in different selection pathways (SS, SD, DS and DD) and different sex-age classes utilizing gene flow theory [14]. The combination of sex-age classes for the relevant pathway was derived from Joezy-Shekalgorabi *et al*. (2010) [15].

Time horizon of 70 years was chosen for economic evaluation. The reason was that reaching to asymptotic phase of genetic improvement was long [16] due to a high number of sex-age classes in reproductive population in Iranian Holstein [15].

All returns and costs were discounted to their net present value. Interest rates were chosen 6 and 8 percent for costs and returns, respectively. Utilized economic parameters are summarized in table 2. According to the economic efficiency of different selection schemes, the optimum combination of progeny group size and test capacity for reaching to the greatest cost-benefit ratio was investigated. Finally, characteristics of optimum schemes for reaching to the highest amount of genetic improvement and economic efficiency were compared.

RESULTS AND DISCUSSION

In the current status of progeny testing scheme of Iran, the progeny group size for testing young sampled bulls and test capacity are 100 and 0.2, respectively. The expected rate of inbreeding in the population was 8.07% per generation. Assuming a generation interval of 6 years for Iranian Holstein, Rokouei *et al*. (2010) obtained inbreeding rates of 1.86% and 1.26% per generation during 2000 to 2007 for females and males, respectively [17]. Results of the current study indicate an average inbreeding rate of 5 times higher than that of reported by Rokoei *et al*. (2010). The overestimation of inbreeding rate in the current study proposes that in reality much more sires are utilized for producing young bulls as they have major effect on increasing the inbreeding rate. On the other hand Rokouei *et al*. (2010) mentioned that the current inbreeding rate is higher than the reported inbreeding rate of Holsteins in US or Canada [17]. This means that in spite of less intense use of sires in practice, a few number of founders produce the genetic makeup of the population.

Genetic improvement considering inbreeding effect in the model was 4.89 genetic standard deviation per generation or 122.85 kg per year. (Considering 540 kg genetic standard deviation [18] and 5.37 years of generation interval [15]). Comparing this value with the amount reported by Joezy-Shekalgorabi *et al*. (2010) [8] demonstrate an overestimation of 4.12% in their study which is resulted from the impact of inbreeding on decreasing genetic variation. On the other hand other studies [19] have reported less genetic trend for Iranian Holsteins. Different factors, such as higher proportion selected specially in SS and DS pathways, variation in family size, use of traits other than milk yield in selection goal and ineffective selection infrastructure lead to lower realized genetic improvement comparing to its expected value.

Progeny group size and test capacity had the same optimum value for obtaining maximum genetic improvement with their value before including inbreeding in the model [8] (Table 3). However, inbreeding had an average impact of -4% on genetic improvement. This indicate that ignoring inbreeding effect in the model, do not have any influence on the optimum combination of factors affecting the maximum genetic improvement, but it overestimates the genetic superiority.

Table 3: Genetic improvement (in the unit of genetic standard deviation per generation) before (ΔG_b) and after (ΔG_a) including inbreeding rate (ΔF) in the model in different progeny group size (n) and test capacity (p)

	n	P	ΔG_b^*	ΔF	ΔG_a	Loss of ΔG due inbreeding%
Base situation	100	0.2	5.10	0.0807	4.89	4.12
n	46	0.2	5.25	0.0805	5.04	4.00
P	100	0.3	5.21	0.0806	5.00	4.02
n and p	57	0.3	5.28	0.0805	5.07	3.98

*Joezy-shekalgorabi, *et al.*, 2010 [8]

Table 4: Optimum progeny group size (n) and number of sampled young bulls (nYB) in different test capacities (P) for reaching to the maximum genetic improvement (ΔG) in selection program

P	n	nYB	ΔF	ΔG	Cost Benefit Ratio	Profit onset (year)
0.1	34	105	0.0806	4.83	2.06	16
0.2	46	155	0.0805	5.04	1.62	20
0.3	57	188	0.0805	5.07	1.40	23
0.4	66	216	0.0805	5.02	1.24	28
0.5	77	232	0.0805	4.93	1.14	33
0.6	88	243	0.0805	4.81	1.06	43
0.7	101	247	0.0805	4.66	0.99	-
0.8	116	246	0.0805	4.49	0.93	-

Table 5: Optimum progeny group size (n) and number of sampled young bulls (nYB) in different test capacities (P) for reaching to the maximum Cost Benefit Ratio in selection program

P	n	ΔF	nYB	ΔG^*	Cost Benefit Ratio	Profit onset (year)
0.1	142	0.0812	26	4.24	3.16	13
0.2	276	0.0812	26	4.32	2.85	14
0.3	414	0.0812	26	4.33	2.58	14
0.4	565	0.0812	26	4.30	2.36	15
0.5	737	0.0813	25	4.25	2.17	16
0.6	941	0.0813	23	4.17	2.00	17
0.7	1194	0.0814	21	4.07	1.85	18
0.8	1520	0.0815	19	3.94	1.70	19

*genetic improvement in the unit of genetic standard deviation

In the schemes with lower genetic improvement, the rate of loss of genetic improvement due to inbreeding was slightly lower than that of schemes with higher genetic improvement. Decreasing progeny group size and test capacity does not have any effect on number of selected SS but would increase the number of selected young bulls and this leads to increase in the number of selected DS which consequently results in more effective population size and less inbreeding in schemes with more genetic improvement. Of course, because of massive usage of a few numbers of sires in SS pathway (1-2 sires) change in effective population size was negligible in different schemes.

To overwhelm the negative effects of inbreeding on genetic improvement, use of more sires for increasing the effective population size is inevitable [7]. Optimized contribution selection has been shown to be a promising tool for achieving to the same genetic improvement at a lower rate of inbreeding [20].

Table 4 represents the optimum progeny group size in different test capacities for reaching to maximum genetic improvement. Cost-benefit ratios which were obtained by dividing net present value of returns to net present value of costs from one round of selection, consider flow of genes in a time horizon of 70 years. Due to small progeny group size, a large number of young bulls need to be sampled for different selection schemes. This is resulted from the reverse relation between progeny group size and number of possible sampled young bulls in a fixed test capacity [11]. Large number of sampled young bulls increases selection intensity in sire pathways. But on the other hand it leads to selection of more DS and less accuracy of selection of SS in a specific test capacity.

Although the highest amount of genetic improvement was reached in test capacity of 0.3 and a progeny group size of 57, this combination did not lead to the highest economic efficiency. The highest cost-benefit ratio among different combination of progeny group size and test capacity for reaching to the maximum genetic improvement was obtained at the least test capacity with a progeny group size of 34 (Table 4). Under this scheme, profit onset was at year 16. While schemes with high test capacities not only led to less economic efficiency, but also some of them never started to be profitable even after 70 years. The most important reason for less economic efficiency of schemes with higher test capacity is related to the large number of sampled young bulls on relevant schemes. In fact, the most significant factor on the cost of a progeny testing scheme is correlated to buying, feeding and maintaining young bulls up to the end of testing process.

Conditions for reaching to the most economic efficiency in different test capacities are presented in table 5. The most cost-benefit ratio was reached at the least test capacity. Comparing these results to the results of table 4, represents a significant difference in number of sampled young bulls and progeny group size. For reaching to the highest possible economic efficiency, the most effective way is to decrease number of sampled young bulls. Because this factor is the key factor in increasing the costs of progeny testing program [9]. However for reaching to an acceptable value of genetic improvement, it is not possible to extremely decrease the number of sampled young bulls because this also could lead to large decrease in selection intensity in sire pathways which cannot be compensated by cost-effectiveness of the program.

Cost-benefit ratio was approximately 4% lower when considering inbreeding effect in the model. Progeny group size for obtaining maximum economic efficiency was similar to its value before including inbreeding in the model. However negligible decrease was observed in number of daughters per sampled young bulls for test capacities of 0.3 to 0.8. The reason could be due to the slight decrease of number of sampled young bulls for reaching to maximum economic efficiency. Optimized contribution selection method emphasizes more on optimized contribution of sires in breeding population. It seems that even with an optimized contribution selection, the optimum combination of progeny group size to be similar to the current results. Because progeny group size of sampled young bulls is not influenced by the number of selected SS but they have the most impact on number of selected DS. Therefore plans like MOET which change the contribution of selected DS probably could affect the optimum combination of progeny group size and test capacity.

The value of inbreeding rate in schemes with the most economic efficiency in different test capacities was slightly higher to their corresponding value of test capacity for schemes with the greatest genetic improvement. This increase in inbreeding rate is related to higher progeny group size which has lead to less number of selected young bulls in the related test capacity. Less number of sampled young bulls needs less number of selected DS which lead to less effective population size. Due to slight effect of DS on effective population size, change in inbreeding as a result of decrease in number of selected DS was negligible.

CONCLUSION

Inbreeding did not have considerable impact on optimum combination of progeny group size and test capacity. However, considering its effect in genetic improvement equation interferes from overestimation of expected genetic superiority and economic efficiency of selection program. Widespread use of a few popular AI sire is a potential for the increased inbreeding in the recent years. Optimized contribution selection has been appeared to be a suitable selection tool not only for managing inbreeding rate, but also for increasing genetic improvement at the same inbreeding rate. Optimized contribution selection could affect the rate of inbreeding by changing the contribution of sires or dams in a selection scheme. However, it seems that optimum combination of progeny group size and test capacity to be unchanged if the optimization be practiced at sire pathway.

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