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Effect of Diverse Sire Origins on First-Parity Performance in Iranian Holstein Cows

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Abstract: The aim of this study was to compare, the effect of diverse sire origins on first lactation performance, Age at First Calving (AFC), first-parity calving class and days open and also Length of Productive Life (LPL) in Iranian Holstein cows. Data regarding to the all first-calving cows were collected during 1996, until 2007 in five large commercial Holstein farms. Farms were located in Northeastern of Iran. Each cow has been characterized by demographic data, production and reproduction data. The dependent variables analyzed were the cumulative first 60, 100 and 200 days as well as 305 days adjusted milk productions, AFC, calving class (including eutocia, dystocia, stillbirth and abortion), days open and LPL. Data were analyzed using mixed models. The effect of the sire origins on calving class was evaluated by nominal logistic analysis. The result showed that first-parity milk performance was similar among the daughters of sire groups ($p>0.05$). Milk production was numerically higher for the imported sire groups. Milk persistency was better for the imported sires compare with the domestic sourced sires ($p<0.05$). Sire origin had no apparent effect on AFC, first-parity calving class and interval from first calving to conception ($p>0.05$). AFC was decreased and days open was increased over the years ($p<0.05$). The cumulative 60 days milk production had no apparent effect on first-parity days open but days open tended to increase in the high producer cows ($p = 0.14$). Length of productive life was higher among the daughters of Iranian sires compare with the Canadian sires ($p = 0.02$). The similar production performance among the daughters of sire origin in this study could be a help in reducing on-farm expenses in Iranian dairy industry. More studies needed to evaluate the results of this study in different climates of Iran along with a larger data set.

Key words: Dairy cow, sire origins, milk performance, age at first calving, length of productive life, Iranian Holstein

INTRODUCTION

Iran has a cattle population of 7.9 million of which 45.9, 43.6 and 10.51% are of the indigenous, crossbred and registered (mainly Holstein) genotypes. The contribution of livestock to the national economy is 4% of total GDP. Iranian dairy production has undergone significant and considerable structural changes during the last two decades FAO (1993) with creation of larger herds. According to the FAO (1993) report, AI coverage in several countries including Iran increased remarkably over the 1980s decade. In general, four groups of sire in terms of their origin are available to dairy producers through AI in Iran. These are American, Canadian, European and Iranian sires, which regardless of their origin can be further categorized to two groups: summarized or sampling sires. Summarized sires are those that have been progeny tested; thus, an estimate of their daughter's producing ability is available. Sampling sires are those that have been selected to transmit high production qualities or type-related traits based on their pedigree. However, they also need to be progeny tested to determine more accurately which sires will pass their high production and type-related traits to their daughters.

Many Iranian dairy producers are reluctant to use foreign sampling sires because their daughters performance is considered somewhat unpredictable. However, Iranian sampling sires are very reasonable and hence, some farmers prefer to use them on the repeat breeder cows as well as on the moderate to low prouder cows.

Among the sires sourced from all over the world, there has been an increase interest in using the North American Holstein semen in Iran as in several other environments (Menjo *et al*., 2009; Dillon *et al*., 2006). That is why, the American and Canadian origin sires have been dominated in the market of overseas sire sources. However, despite the evidence that global selection can increase rates of genetic progress in dairy cattle by up to 17% compared to within country and breed selection (Dillon *et al*., 2006), concerns have been raised about the effects of Genotype by Environment interaction (G×E)

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especially in subtropical and tropical environments (Menjo *et al*., 2009). Although, there is some concern that the effects of G×E tend to lo wer productivity of most exotic dairy breeds in tropical and subtropical environments relative to the country of origin (Menjo *et al*., 2009; Ojango and Pollott, 2002), there are other studies that showed genotype-climatic interactions were of no consequence for production performance. Powell and Dickinson (1977) reported that the cows imported into Mexico from the United States or Canada were superior to nonimported Holsteins.

There are some reports on the effect of sire origin on milk performance, however, up to now there is lack of accurate and specific information on the reproductive performance of the imported semen in Iran.

The aim of this study was to compare the effect of diverse sire origins on first-parity performance in Iranian Holstein cows.

MATERIALS AND METHODS

Data regarding to the all first-calving cows were collected during 1996, until 2007 in five large commercial Holstein farms. During the period, the median number of cows in the study herds was 350. Farms were located in Northeastern of Iran and were enrolled in the official milk-recording scheme. The farm selection was done among those affiliated with at least one of dairy cooperatives and was also based on the farmer's willingness to cooperate in the study. Each farmer had dairy management software in farm to collect the data and manage all dairy operations. Farmers have recorded information about all existing and culled cows. Each cow has been characterized by demographic data (birth date, sire, first calving date), production data (cumulative first 60, 100 and 200 days as well as 305 days adjusted milk productions) and reproduction data (calving class, sex and weight of calf at calving, next breeding information, days open). Collected data were checked for consistency of data. Finally, during the study period, a total of 5204 first lactation cows were used.

Herds were characterized by dummy variables. The dependent variables analyzed were the cumulative first 60, 100 and 200 days as well as 305 days adjusted milk productions, milk persistency, Days Open (DO), Age to First Calving (AFC) and also, Length of Productive Life (LPL). Milk persistency was measured by dividing the cumulative 100 days milk production by the 60 days milk production (M 100-days/M 60-days) and the same method for calculating M 200-days/M 100-days.

Sires were grouped into various categories depending on their area of origin. In total, four groups were defined; Iran, Canada, USA and others, which include sires originating from European countries. Because of low number of sires originating from European countries, this group was omitted from final data for the statistical analysis.

The length of productive life was defined as the interval from first calving to the date of death or culling on the farm. Animal records used for the analysis had to have a date of first calving and a date of death or culling from the herd.

Initially, age at first calving was between 17 and 41 months, but due to the low number of some levels was re-grouped as 22 month and less 23-38 month (1/month) and 39 and more month.

The model for analyzing cumulative and 305 days adjusted milk yields as well as milk persistency included the herd, sire origin with 3 levels, calving year and season, AFC, calving class with 4 levels (including eutocia, dystocia, stillbirth and abortion) and calving sex effects.

The factors included in the model for analyzing days open were herd, sire origin with 3 levels, calving year and season (AFC) cumulative first 60 days milk production with 4 levels (<1644, 1644-2036, 2037-2405 and >2405 kg), calving class with 4 levels (including eutocia, dystocia, stillbirth and abortion) and calving sex effects. For analyzing the length of productive life the model included the first parity 305 days adjusted milk yield instead of the different 60 days milk production levels. The other model components were similar to the model for analyzing days open. The model for analyzing effect of sire origins on AFC included herd, calving year and season, calving class with 4 levels (including eutocia, dystocia, stillbirth and abortion) and calving sex effects.

Data were analyzed using mixed models in SAS (2001). The means were separated using Turkey HSD multiple range test. Least squares means are reported throughout and significance was declared at $p<0.05$. The distribution analyze for the variables was done using the statistical software package JMP (SAS Institute Inc., NC, USA). Logistic models were used to analyze the impact of origin of sires and other mentioned factors on first-parity calving class.

RESULTS

Age at first calving averaged 27.29±3.1 month. The median was 27 month and 25 and 75% quartiles were 25 and 28 month, respectively. Its distribution showed almost a bell shape but the goodness of fit test rejected a normal distribution (Fig. 1).

Cumulative 60, 100 and 200 days milk productions averaged 1714.6±404, 2851.1±659 and 5516.9±1258 kg, respectively. The cumulative 60 days milk production

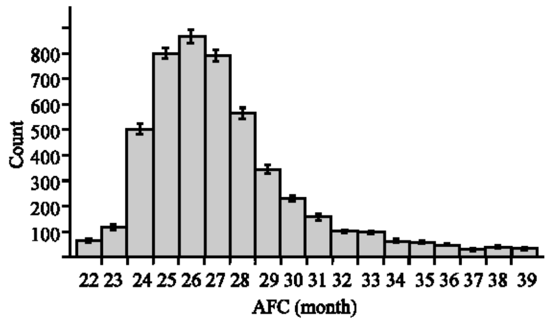

Fig. 1: Age at First Calving (AFC) in month in the Iranian Holstein cows (SE = 0.044)

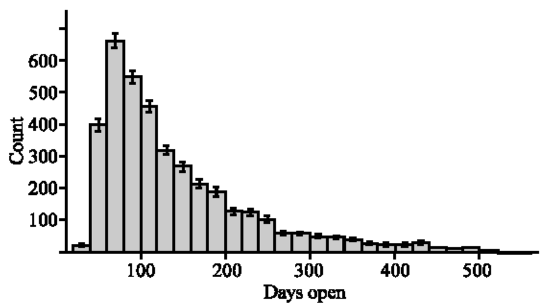

Fig. 2: Days open in day after first calving in the Iranian Holstein cows (SE = 1.48)

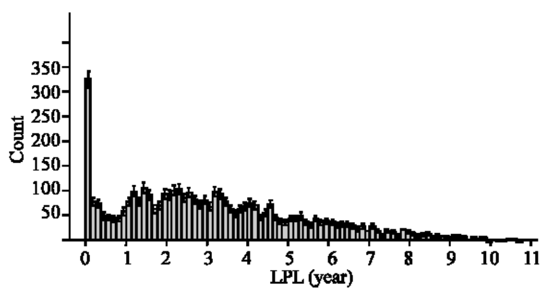

Fig. 3: Length of Productive Life (LPL) in year in the Iranian Holstein cows (SE = 0.04)

median was 1723.6 kg and 25 and 75% quartiles were 1449.5 and 1983.1 kg, respectively. The cumulative 100 days milk production median was 2853.0 kg and 25 and 75% quartiles were 2409.0 and 3295.3 kg, respectively. The cumulative 200 days milk production median was 5542.1 kg and 25 and 75% quartiles were 4650.0 and 6373.4 kg, respectively. Their distribution showed a bell shape and the goodness of fit test approved a normal distribution.

The 305 days adjusted milk yield averaged 7410.6±1912 kg. The median was 7424.0 kg and 25 and 75% quartiles were 6094.0 and 8717.0 kg, respectively. Its distribution showed a bell shape and the goodness of fit test approved a normal distribution.

The interval from first calving to conception, days open, averaged 142±92 days. The median was 111.5 days and 25 and 75% quartiles were 76 and 179 days, respectively. Figure 2 shows its distribution.

Length of productive life averaged 3.22±2.31 year. The median was 2.86 year and 25 and 75% quartiles were 1.41 and 4.63 year, respectively. Its distribution showed almost a unimodal shape and a progressive decrease (Fig. 3).

AFC was similar among the sire origin ($p = 0.42$; 26.81±0.25, 26.76±0.27 and 26.62±0.28 month, respectively for Iranian, Canadian and American sires). The effect of herd, calving year and season and also calving class were significant on the age at first calving ($p<0.05$). AFC decreased over the time ($p<0.001$). Cows calved for the first time during winter had a significant higher AFC compare with the spring cows ($p = 0.03$; 26.2±0.3, 26.8±0.3, 26.9±0.3 and 27.1±0.3 months, respectively for Spring, Summer, Autumn and Winter). First-parity calving class impacted AFC and cows with abortion status had the lowest AFC ($p = 0.002$; 26.9±0.2, 27.2±0.4, 27.2±0.3 and 25.5±0.5 months, respectively for eutocia, dystocia, stillbirth and abortion).

The cumulative 60 and 100 days milk productions were all similar among the sire origin ($p>0.05$, Table 1). The milk yields were impacted by the herd, calving season and year, calving class and AFC ($p<0.05$).

The cumulative 200 days milk productions was numerically higher in daughters of American sires ($p = 0.08$; Table 1). The milk yield was impacted by the herd, calving season and year and calving class. AFC had no apparent effect on cumulative 200 days milk production ($p = 0.10$).

The adjusted 305 days milk production was similar among daughters of different sire origins ($p = 0.15$; Table 1). Herd, calving season and year and calving class had significant impact on the adjusted 305 days milk production ($p<0.05$).

Milk persistency measured as the cumulative 100 days milk production divided by the cumulative 60 days milk yield was different among the sire origins ($p = 0.025$; Table 1) and the daughter of Canadian sires had a better persistency compare with the Iranian sires. The Canadian and American sires performed similarly. The persistency was also impacted by herd and calving year ($p<0.05$). The milk persistency measured by the cumulative 200 and 100 days milk productions was also different between Canadian and Iranian sires ($p<0.01$) and similar among the American and Canadian sires ($p>0.1$; Table 1). Herd, calving year, AFC and calving class had significant impact on the persistency.

Table 1: The impact of diverse sire origins on production performance of Iranian Holstein cows

	Sire origin			
Items	Iranian	Canadian	American	p- value
Cumulative 60 days milk production, kg (M 60-days)	1560.5±32.00	1537.9±48.00	1644.6±70.00	0.390
Cumulative 100 days milk production, kg (M 100-days)	2582.7±54.00	2640.5±80.00	2765.9±111.0	0.220
Cumulative 200 days milk production, kg (M 200-days)	4865.8±99.00	5084.8±146.0	5244.8±206.0	0.090
Adjusted 305 days milk production (kg)	6648.0±152.0	7054.3±227.0	6996.1±330.0	0.150
Milk persistency: M 100-days/M 60-days	1.65±0.01	1.70±0.01	1.66±0.02	0.020
Milk persistency: M 200-days/M 100-dyas	1.89±0.01	1.96±0.02	1.93±0.03	0.002

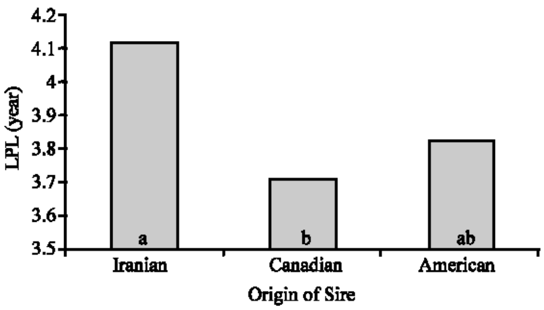

Fig. 4: Length of Productive Life (LPL) among the daughters of Iranian (SE = 0.19), Canadian (SE=0.22) and American sires (SE = 0.27)

Sire origin had no effect on the interval from first calving to conception (p = 0.21; 145.0±9.5, 151.3±9.7 and 152.1±10.2 days, respectively for Iranian, Canadian and American sires). The effect of herd, calving year and season and calving class were significant on the days open ($p<0.05$). The cumulative 60 days milk production had no apparent effect on days open but days open tended to increase in the high producer cows (p = 0.14; 144.07±9.1, 143.06±9.5, 152.9±10.0 and 157.7±12.6 days, respectively for <1644, 1644-2036, 2037-2405 and >2405 kg cumulative 60 days milk production). Days open was increased during the years (p = 0.02). Calving season impacted the days open. DO was lowest for the cows calved during summer (p = 0.26; 152.31±9.7, 142.0±9.8, 147.9±9.8 and 155.5±9.8 days, respectively for Spring, Summer, Autumn and Winter).

The sire origin impacted the length of productive life (p = 0.023). LPL was greatest among the daughters of Iranian sires and lowest for the daughters of Canadian sires ($p<0.05$; Fig. 4).

Among the main effects, calving year and season, AFC and calving class impacted LPL ($p<0.05$). The herd effect was not significant (p = 0.07). LPL was reduced during the time ($p<0.01$). Increase in AFC decreased LPL smoothly ($p<0.05$). Eutocia status in the first calving significantly increased LPL compare with stillbirth ($p<0.05$; 4.05±0.16, 3.57±0.29, 3.57±0.24 and 4.32±0.35 year, respectively for eutocia, dystocia, stillbirth and abortion).

Origin of sire had no apparent effect on calving class in the first calving (p = 0.65). Herd, calving year and season and AFC impacted the calving class ($p<0.05$).

DISCUSSION

The most striking observation of this study was the similar first parity milk productions, AFC and first-parity days open among the different sire origins. This might be due to a proper sire selection and evaluation in Iran. Sire has more influence on herd improvement than any one female and hence sire selection should be treated as a top priority to increase herd profitability. According to a rough estimation, from the dairy farms located in Northeastern of Iran, at least 50% of all inseminations of Holstein cows used Iranian Holstein sires, which just about 30% of those are summarized sires (A. Shariatpour, personal communication). The cost of an Iranian Holstein semen straw averages about 3500 Tomans (US $1 = 968 Tomans) for summarized and 1200 Tomans for sampling sires compare with 18000 Tomans for imported semen. The similar production performances among the daughters of sire origins in this study could be a help in reducing on-farm expenses in Iranian dairy industry.

The dairy farms, which their data were used in this study located in Northeastern of Iran with a temperate climate. It was a concern about the effects of Genotype by Environment interaction (G×E) especially, in subtropical and tropical environments (Menjo *et al*., 2009). Although, this kind of interaction was shown in different parts of Iran representing different climates (Salimi, 2003), other studies showed no such interaction of practical importance for different definitions of environment within countries (Wiggans and Van Vleck, 1978; De Veer and Van Vleck, 1987). Some studies were conducted to compare different environments based on daughters of the same sire in different countries (Powell and Dickinson, 1977; Carabaño *et al*., 1989). In agreement with the results, it was shown that genetic progress for milk yield can be achieved by using superior germ plasm regardless of origin (Powell and Dickinson, 1977).

Result of current study showed that age at calving averaged 27.29±3.11 month and was similar among the origin of sires. In the life cycle of a female farm animal, AFC represents a truncation point when an animal's status changes from an input-based resource to a productive asset for a producer (Ettema and Santos, 2004). It has been estimated that the cost of rearing animals up to AFC constitute 15-20% of the total expenses related to milk production in temperate production systems (Heinrichs, 1993). In the United States, the average AFC of dairy cattle (mostly Holsteins) between 1985 and 1990 was 25.9 months (Heinrichs *et al*., 1994). A similar AFC among the sires might be due to a similar growth rate of the heifers. The results of present study also showed that AFC was impacted by herd effect. The variation observed in AFC for the different herds clearly reflected differences in management practices as well as herd size. It was shown that mean age at first calving in 2002 was inversely related to herd size (USDA, 2002) and within herd was 25.5 months when herd size was <100 cows, but only 24.6 months when herd size was = 500 cows. Our recent study on the impact of age at first calving on production and reproduction performances addressed the impact of other factors on AFC (Heravi and Mesgaran, 2008).

First-parity days open was similar among the sire origins. Days open could be impacted by milk production. High milk yield requires high dietary intake and altered patterns of metabolism (Gutierrez *et al*., 2006) as well as a reduction in circulating steroids because of greater breakdown and clearance of both estradiol and progesterone (Wiltbank *et al*., 2006) and these outcomes seem to be associated with subfertility (Chagas *et al*., 2007). Reduced circulating concentrations of progesterone are associated with reduced pregnancy rates (McNeill *et al*., 2006). In the present study, similar milk production among the sire origins may explain, at least partly, similar days open in the first lactation.

AFC can also affect first calving days open. Ettema and Santos (2004) reported that conception rate and days open were affected by age of calving. The study found higher first postpartum AI conception rates and lower days open in the medium (AFC = 701-750 days) compared to either the low (AFC = 700 days) or high (AFC >750 days) age groups. Evans *et al*. (2006) also, showed a tendency towards lower subsequent CI in cows calving for the first time at ages of 25-26 months compared to both younger and older age groups at first calving. In agreement with their results, the present study showed no difference in AFC among the sire groups, which could be a complementary explanation for a similar first-parity days open.

Increased days open over the years in the present study is in consistent with other reports that showed days from calving to conception increased in the last half of century (Lucy, 2001).

LPL was impacted by the sire origin and was lowest in the daughters of Canadian sires compare with daughters of Iranian sourced sires. This might be due to a non-significant higher amount of milk production in this group. A shorter than expected stay of high producing cows in the herd may be explained by culling for reasons other than production such as health disorders and unsatisfactory reproductive performances (involuntary culling). In a recent study, it was shown that diseases and reproductive disorders were the main reasons for culling in Iranian Holstein cows (Heravi, 2008a). These results are comparable to findings by Ducrocq (1994), Weigel *et al*. (2003) and Ajili *et al*. (2007). On the other hand, harsh conditions in the summer (heat stress) and food shortages in some cases may compromise performances of cows with high potentials for milk production (Ajili *et al*., 2007). Culling influences profitability of dairy production by affecting herd life, replacement rates and milk yield (Weigel *et al*., 2003). In a study, on French dairy herds, Seegers (1998) estimated that a 5% increase in the culling rate induced a 20% increase in replacement cost/L of milk produced in the affected herd. High culling rates also contribute to reduced profitability of dairy herds by reducing percentage of the cows producing at mature levels because of early quit (Beaudeau *et al*., 2000). Decreased LPL in the daughters of North American sires, especially Canadian sires in the present study emphasize on the importance of high producing cows management. The results of present study is in contrast to our other report on the effect of sire origin on LPL (Heravi, 2008b). The sires within each regional group in the present study is more accurate than the previous one.

LPL was similar among the herds in this study. Dairy cows may be culled for either involuntary reasons (i.e., mastitis, extreme lameness, poor reproduction, death, acute disease and so on) or voluntary reasons (i.e., dairy purposes or deemed normal except than they were poor producers). Similar LPL among the herds might be due to more involuntary culling than the voluntary reason for culling. On the other hand, decreased in LPL during the recent years also showed that in general, the mean risk to cull cows tends to increase slightly from 1 year to the next. This increase could be explained by more intensive selection in the recent years. As cows have improved, culling standards have been raised. A downward environment trend has occurred because cows that once were competitive now would be culled.

CONCLUSION

The results of this study demonstrated an acceptable first-parity performance of Iranian sourced Holstein sires compare with the North American sires. The imported sires had a better milk persistency and a numerically higher milk production compare with the domestic sourced sires. Reproductive performance measured as AFC and also first-parity calving class and days open were all similar among the sire groups. Reduced LPL in the daughters of Canadian sires might be related to their higher milk production. Although, use of North American semen likely would increase milk yield, economic costs and benefits should be compared with Iranian sire. Further investigation is necessary to evaluate the results of present study in different climates of Iran and with a larger number of cows.

REFERENCES

Ajili, N., B. Rekik, A. Ben Gara and R. Bouraoui, 2007. Relationships among milk production, reproductive traits and herd life for Tunisian Holstein-Friesian cows. Afr. Can. J. Agric. Res., 2: 47-51.

Beaudeau, F., H. Seegers, V. Ducrocq, C. Fourichon and N. Bareille, 2000. Effect of health disorders on culling in dairy cows: A review and a critical discussion. Ann. Zootech., 49: 293-311.

Carabaño, M.J., L.D. Van Vleck, G.R. Wiggans and R. Alenda, 1989. Estimation of genetic parameters for milk and fat yields of dairy cattle in Spain and the United States. J. Dairy Sci., 72: 3013-3022.

Chagas, L.M., J.J. Bass, D. Blache, C.R. Burke, J.K. Kay, D.R. Lindsay, M.C. Lucy, G.B. Martin, S. Meier, F.M. Rhodes, J.R. Roche, W.W. Thatcher and R. Webb, 2007. Invited review: New perspectives on the roles of nutrition and metabolic priorities in the subfertility of high-producing dairy cows. J. Dairy Sci., 90: 4022-4032.

De Veer, J.C. and L.D. Van Vleck, 1987. Genetic parameters for first lactation milk yields at 3 levels of herd production. J. Dairy Sci., 70: 1434.

Dillon, P., D.P. Berry, R.D. Evans, F. Buckley and B. Horan, 2006. Consequences of genetic selection for increased milk production in European seasonal pasture based systems of milk production. Livest. Sci., 99: 141-158.

Ducrocq, V., 1994. Statistical analysis of length of productive life for dairy cows in the Normande breed. J. Dairy Sci., 77: 855.

Ettema, J.F. and J.E.P. Santos, 2004. Impact of age at calving on lactation, reproduction, health and income in firstparity Holsteins on commercial farms. J. Dairy Sci., 87: 2730-2742.

Evans, R.D., M. Wallace, D.J. Garrick, P. Dillon, D.P. Berry and V. Olori, 2006. Effects of calving age, breed fraction and month of calving on calving interval and survival across parities in Irish spring-calving dairy cows. Livest. Sci., 100: 216-230.

FAO, 1993. Survey of present status of the use of artificial insemination in developing countries. World Anim. Rev., 74/75,U9550/T.

Gutierrez, C.G., J.G. Gong, T.A. Bramley and R. Webb, 2006. Selection on the predicted breeding value for milk production delays ovulation independently of changes in follicular development, milk production and body weight. Anim. Reprod. Sci., 95: 193-205.

Heinrichs, A.J., 1993. Raising dairy replacements to meet the needs of the 21st century. J. Dairy Sci., 76: 3179-3187.

Heinrichs, A.J., S.J. Wells, H.S. Hurd, G.W. Hill and D.A. Dargatz, 1994. The national dairy heifers evaluation project: A profile of heifer management practices in United States. J. Dairy Sci., 77: 1548-1555.

Heravi, M.A., 2008a. Days in milk at culling in Holstein dairy cows. J. Anim. Vet. Adv., 7: 89-93.

Heravi, M.A., 2008b. Influences of milk yield and fertility traits in the first lactation on the length of productive life of Holstein dairy cows in Iran. Res. J. Biol. Sci., 3: 1022-1027.

Heravi, M.A. and M.D. Mesgaran, 2008. Impact of age at first calving on lactation and reproduction of first-parity Iranian Holsteins dairy cows. J. Anim. Vet. Adv., 7: 190-195.

Lucy, M.C., 2001. Reproductive loss in high-producing dairy cattle: Where will it end? J. Dairy Sci., 84: 1277-1293.

McNeill, R.E., M.G. Diskin, J.M. Sreenan and D.G. Morris, 2006. Associations between milk progesterone concentration on different days and with embryo survival during the early luteal phase in dairy cows. Theriogenology, 65: 1435-1441.

Menjo, D.K., B.O. Bebe, A.M. Okeyo and J.M.K. Ojango, 2009. Analysis of early survival of Holstein-Friesian heifers of diverse sire origins on commercial dairy farms in Kenya. Trop. Anim. Health Prod., 41: 171-181.

Ojango, J.M.K. and G.E. Pollott, 2002. The relationship between Holstein bull breeding values for milk yield derived in both the UK and Kenya. Livestock Prod. Sci., 74: 1-12.

Salimi, F., 2003. The study of imported bull genetic performance in different climates of Iran. MSc. Thesis. University of Mazandaran, Mazandaran, Iran.

SAS User's Guide. Statistics, Version 8.2. Edn. 2001. SAS Inst., Inc. Cary, NC.

Seegers, H., F. Beaudeau, C. Fourichon and N. Bareille, 1998. Reasons for culling in French Holstein cows. Prev. Vet. Med., 36: 257-271.

Powell, R.L. and F.N. Dickinson, 1977. Progeny tests of sires in the United States and in Mexico. J. Dairy Sci., 60: 1768-1772.

USDA, 2002. Dairy, 2002. Part I: Reference of dairy health and management in the United States, 2002. Rep. N377.1202. National Animal Health Monitoring System, Animal and Plant Health Inspection Service, USDA, Fort Collins, Co.

Wiggans, G.R. and L.D. Van Vleck, 1978. Evaluation of sires in herds feeding differing proportions of concentrates and roughage. J. Dairy Sci., 61: 246.

Weigel, K.A., R.W. Palmer and D.Z. Caraviello, 2003. Investigation of factors affecting voluntary and involuntary culling in expanding dairy herds in Wisconsin using survival analysis. J. Dairy Sci., 86: 1482-1486.

Wiltbank, M., H. Lopez, R. Sartori, S. Sangsritavong and A. Gumen, 2006. Changes in reproductive physiology of lactating dairy cows due to elevated steroid metabolism. Theriogenology, 65: 17-29.