What is the best first-calving age of cows in robotic milking farms?

Gürkan İlhan, Enver Çavuşoğlu and Abdulkadir Orman

Department of Animal Sciences, Institute of Health Sciences, Bursa Uludag University, Nilufer/Bursa, Turkey; Department of Animal Sciences, Faculty of Veterinary Medicine, Bursa Uludag University, Nilufer/Bursa, Turkey

ABSTRACT

The aim of this study is to determine the effect of first-calving age (FCA) on yield parameters and productive life in dairy farms using a robotic milking system in Turkey. The cows (n = 1579) were divided into five groups (24, 25, 26, 27, 28 months and above FCA). The average milk yield was highest in 24 months of FCA (9140.31 ± 145.55 kg) and was lowest in 27 months of FCA (8534.55 ± 131.00 kg) (p < .05). The average service period length in the first lactation was longer in cows of 28 months old (158.92 ± 7.28 days) than 26 and 27 months (131.96 ± 4.45 and 130.51 ± 5.497 days respectively) old groups (p < .05). A number of lactations of cows that were 26 months old (2.52 ± 0.09) at FCA was higher than those FCA was 24 months and 28 months (2.03 ± 0.15 and 2.18 ± 0.09 respectively) (p < .05). Replacement rates were not differing statistically at different lactations. The most frequent reasons for culling were mastitis and reproduction in all groups. As a result, cows in 24 months of FCA had no undesirable results in terms of milk yield, service period, number of insemination per lactation.

ARTICLE HISTORY

Received 14 September 2021
Revised 13 January 2022
Accepted 14 January 2022

KEYWORDS

Robotic milking; first-calving age; milk production; reproductive parameters; longevity

Introduction

Increasing labour rates and the difficulty of finding qualified personnel in Turkey as well as in developed countries push the farmers to invest in automation in dairy cow operations. More than half of the labour requirement in dairy cow farms is due to the milking process. Robotic milking systems are, parallel to the world, becoming increasingly common in Turkey. The first robotic milking system was used in Dutch dairy farms in 1992 (De Koning et al. 2003). The reason why the robotic system has started in western European countries is that dairy farm sizes are relatively small compared to US and labour costs are very high. Robotic milking is more appropriate in medium-sized enterprises as individual tracking of cows is more difficult in bigger farms. Since most of the dairy farms in Turkey are small or middle-size farms, the robotic milking system has potential in the future of the dairy sector in Turkey. A significant reduction in the need for labour encourages entrepreneurs to invest in the use of milking robots. However, it is still unknown how factors that fundamentally affect profitability, such as yield parameters and productive life change or may change in these systems.

Automation in animal production not only lowers the labour cost but also minimises the mistakes or negligence of farm staff. Hansen (2015) reported in a survey study in Norway that the main reason of farmers to use robotic milking is that this system gives farmers a more flexible time and reduces the work intensity. This creates more time for farmers to spend time on improving management. Cows go to milking voluntarily in a robotic milking system which increases the number of milking per day. Milk yield increases between 6% and 25% if the number of milking per day increases from twice a day to three times a day (Erdman and Varner 1995). However, the lameness problem should be monitored carefully since the lame cow would tend to go milking less than other cows. Siewert et al. (2018) reported that more frequent milking in robotic milking farms increases productivity. Furthermore, the same study found that feed push-up by automatic robots increases the milk yield in cows since robots push the feed more frequently than farm staff. Kruip et al. (2002) found that robotic milking has increased milk production and had no negative effect on the non-return rate on 56-day post insemination but increased the days to the first service. However, the same study found that somatic cell count (SCC)
was not affected by increasing the milking frequency from twice to three times; but SCC increased in robotic milking. Cows go to milking voluntarily without any external force in the robotic milking system which might also be more appropriate in terms of animal welfare. De Koning et al. (2003) reported in an earlier study that SCC increases in the first six months of the introduction of the robotic milking but SCC stabilise after the first six months.

Cows need several weeks to get used to the robotic milking system. Since the replacement rate is more than 20% in modern dairy farms, a large portion of the herd will need to be familiar with the system each year and some cows might have the problem of having robots for milking. However, Örs and Öğuz (2018) concluded in a review study that even though the investment cost and energy usage in the robotic milking system are higher compared to conventional milking parlour systems, robotic milking has increased milk yield and lowered the labour cost. That is why the robotic system has potential in the future dairy sector in especially developed countries where the price of labour is increasing gradually.

Longevity is an important economic parameter since it is related to total profit from a cow (Ducrocq et al. 1988). In general, the longer a cow stays in the herd, the more milk you get from it. On the other hand, genetic progress decreases when longevity increases because of a long generation interval. The first-calving age is an important parameter, which determines the longevity of cows. Nevertheless, smaller and underdeveloped heifers have a higher risk of dystocia (Ettema and Santos 2004). What is more, increasing the milk yield of a cow reduces fertility (Oltenacu and Broom 2010). That is why it is crucial to determine the optimum FCA in heifers in order to have the highest net profit from a cow and the longest productive life.

The cost of raising a heifer is reduced by $51 to $116 if the FCA is reduced for a month (Gabler et al., 2000; Nor et al. 2013). On the other hand, there is a correlation between growth rate and FCA (Le Cozler et al., 2008). If a heifer has not reached a certain body weight and growth rate, reduced milk production and reduced longevity might happen. That is why it is difficult for farmers to decide the best FCA for heifers. Nor et al. (2013) found that FCA is associated with some rearing factors such as the amount of milk given to the calf and the age of the first insemination of the heifer. In a study done by Haworth et al. (2008) in Australia, which is a tropical climate, first lactation milk yield, estimated lifetime production, and Longevity Index (lifetime days in milk divided by its longevity) was recorded the highest in cows, which had FCA of 2 and 2.5 years compared to FCA of less than two years or more than 2.5 years. In the same study, there was a positive correlation between FCA and longevity in cows, which produced less than 30 litres of milk per day. Lifetime milk production was not affected by FCA, but there was a positive correlation between milk yield in the first lactation and lifetime milk yield. Do et al. (2013) found that the best FCA should be between 22.5 and 23.5 months in Holstein cows.

The aim of this study is to determine the effect of FCA on yield parameters and productive life in dairy farms using a robotic milking system in Turkey. There have been no previous studies on the economically optimal first calving age and when to perform the first insemination of heifers in the robotic milking system. This study is the first comprehensive study in robotic milking dairy farms in Turkey.

**Materials and methods**

**Animals**

All procedures were approved by The Ethical Committee of Bursa Uludag University (2018 – 11 – 01). A total of 2233 lactation records of 1579 dairy cattle were used in this study. Lactation records consisted of 1001 1st, 663 2nd, 399 3rd and 170 4th. All animals were imported from USA and/or Germany in 2012 and 2013. The breed of the cows was Holstein. Cow was divided into five groups according to their FCA (24, 25, 26, 27, 28 and above months of age). All four farms had a free-stall housing system. All animals were fed with Total Mixed Ration (TMR) (except 0.5 kg concentrate feed was given on the robot) by ad libitum and access to freshwater.

**Milking robots and procedure**

The data of this study were obtained from four dairy cow operations, all of which use the robotic milking system of the same company (DeLaval VMS™). These farms are located in the Aegean and Marmara regions of Turkey in which most of the dairy animal production takes place. The evaluated period was from 2013 to 2018. All data were obtained through the herd management program (DeLaval DelPro™), which is used in all four operations. All animals are milked by voluntary milking procedure and milking intervals set evenly. The animals that were not milked were detected from the system and brought to the milking
robot by workers. Thus, the animals were milked before the milking interval was extended. All dairy cattle maximum 0.5 kg concentrate feed was given during milking on the robot.

**Statistical analysis**

Performance data (milk yield, service period, number of inseminations per pregnancy and number of lactations) were tested to determine normal distribution by F-test, and One-way ANOVA was used to compare data according to groups. Group was included to model as a factor and the other variables as the dependent variable. Variances were tested by the homogeneity of variances (Levene Statistic) and the other variables as the dependent variable. Group was included to model as a factor and One-way ANOVA was used to compare data according to groups. Group was included to model as a factor and One-way ANOVA was used to compare data accord-

The average milk yield of groups in each individual lactation period was not significantly different (p > .05; Table 1). However, the average milk yield of all four lactation periods was highest in 24 months of FCA and was lowest in 27 months of the FCA group (p < .02).

Average service period length in the first lactation was significantly longer in cows of 28 months old at first-calving than all other groups except 24- and 25-months old groups (p < .03; Table 2). The average service period was not significantly different between all five groups in second, third and fourth lactation.

Number of inseminations for each conception in all four lactation periods was not significantly different between all groups (p > .05; Table 3). Additionally, a

### Table 1. Milk yield (kg) of cows in each lactation period.

| First-calving age (months) | 1st lactation | 2nd lactation | 3rd lactation | 4th lactation | Average |
|--------------------------|---------------|---------------|---------------|---------------|---------|
| n | Mean ± SE | n | Mean ± SE | n | Mean ± SE | n | Mean ± SE |
| 24 | 110 | 7699 ± 136.23 | 80 | 9678 ± 253.44 | 44 | 10915 ± 291.22 | 12 | 11694 ± 636.95 | 246 | 9140.31 ± 145.55 |
| 25 | 251 | 7565 ± 89.81 | 164 | 9136 ± 167.95 | 111 | 10183 ± 201.19 | 54 | 10678 ± 319.20 | 580 | 8831.23 ± 90.87 |
| 26 | 279 | 7548 ± 81.82 | 200 | 9049 ± 165.22 | 125 | 10024 ± 202.69 | 65 | 10199 ± 351.11 | 669 | 8727.65 ± 88.27 |
| 27 | 140 | 7448 ± 124.45 | 89 | 8911 ± 276.19 | 52 | 10159 ± 269.68 | 23 | 10263 ± 455.70 | 669 | 8727.65 ± 131.00 |
| >28 | 221 | 7814 ± 114.82 | 130 | 9309 ± 208.05 | 67 | 10034 ± 249.73 | 16 | 10263 ± 626.41 | 434 | 8757.40 ± 102.11 |
| Overall | 1001 | 7448 ± 10.57 | 663 | 9179 ± 90.59 | 399 | 10186 ± 106.12 | 170 | 10447 ± 194.49 | 2233 | 8779.12 ± 47.26 |

**P Value** > .05

- **Different superscripts in columns indicate statistical significance.**

### Table 2. Service period (days) in each lactation period.

| First-calving age (months) | 1st lactation | 2nd lactation | 3rd lactation | 4th lactation |
|--------------------------|---------------|---------------|---------------|---------------|
| n | Mean ± SE | n | Mean ± SE | n | Mean ± SE | n | Mean ± SE |
| 24 | 118 | 141.81 ± 6.61 | 64 | 106.92 ± 5.66 | 35 | 108.86 ± 5.88 | 8 | 92.50 ± 5.36 |
| 25 | 257 | 136.51 ± 4.92 | 136 | 99.01 ± 3.26 | 85 | 109.79 ± 4.49 | 43 | 107.81 ± 6.83 |
| 26 | 289 | 131.96 ± 4.45 | 158 | 109.14 ± 3.34 | 96 | 103.19 ± 3.76 | 58 | 104.52 ± 5.25 |
| 27 | 142 | 130.51 ± 5.97 | 76 | 106.76 ± 4.66 | 44 | 108.75 ± 6.40 | 20 | 107.80 ± 9.42 |
| >28 | 221 | 158.92 ± 7.28 | 101 | 107.44 ± 4.14 | 63 | 108.11 ± 5.33 | 14 | 95.64 ± 8.37 |
| Overall | 1027 | 139.83 ± 2.70 | 535 | 105.64 ± 1.78 | 323 | 107.26 ± 2.20 | 143 | 104.43 ± 3.34 |

**P Value** < .05

- **Different superscripts in columns indicate statistical significance.**

### Table 3. Number of inseminations per pregnancy in each lactation period.

| First-calving age (months) | 1st lactation | 2nd lactation | 3rd lactation | 4th lactation |
|--------------------------|---------------|---------------|---------------|---------------|
| n | Mean ± SE | n | Mean ± SE | n | Mean ± SE | n | Mean ± SE |
| 24 | 118 | 2.21 ± 0.15 | 64 | 2.00 ± 0.16 | 35 | 2.06 ± 0.16 | 8 | 1.88 ± 0.22 |
| 25 | 257 | 2.11 ± 0.09 | 136 | 1.62 ± 0.07 | 85 | 1.94 ± 0.10 | 42 | 1.95 ± 0.18 |
| 26 | 289 | 2.17 ± 0.09 | 158 | 1.89 ± 0.08 | 96 | 1.97 ± 0.11 | 57 | 1.96 ± 0.13 |
| 27 | 142 | 2.05 ± 0.11 | 76 | 1.87 ± 0.11 | 44 | 1.95 ± 0.14 | 20 | 2.15 ± 0.24 |
| >28 | 222 | 2.40 ± 0.13 | 101 | 1.74 ± 0.10 | 63 | 1.78 ± 0.12 | 14 | 2.07 ± 0.26 |
| Overall | 1028 | 2.19 ± 0.05 | 535 | 1.80 ± 0.04 | 323 | 1.93 ± 0.05 | 141 | 1.99 ± 0.08 |

**P Value** > .05

- **Different superscripts in columns indicate statistical significance.**
number of inseminations for each conception are getting lower by increasing lactation number in all four lactation periods but it was not significant (p > .05). The average number of lactations of cows that were 26 months old FCA was significantly higher than those FCA was 24 months and 28 months (p < .05; Table 4).

Culling rates according to parity at first insemination are shown in Table 5. After the first lactation, 49.2% of cows in the 24 months of FCA were replaced, whereas this rate is 36.8%, 32.9%, 31.5%, and 34.4% in cows of 25, 26, and 27 months of FCA, respectively. The most replacing rate at the end of the first lactation was in the 24 months of FCA, but this difference was not significant (p > .05). 34.4% of cows were replaced after the first lactation in the cows of 28 months or older FCA. Only 11.5%, 15.8%, 13.4%, and 12.0% of cows have stayed for four lactations in 28 months or older FCA. Only 11.5%, 15.8%, 13.4%, and 12.0% of cows have stayed for four lactations in 28 months or older FCA. And none of the animals that gave birth at 24, 27 and 28 months of FCA could reach 6th lactation.

The percentage of culling reasons of cows are presented in Table 6. Mastitis is a culling reason was lowest in the group of 27 months FCA and was highest in the group of 26 months FCA (p < .05). The percentage of cows culled because of reproduction problems was lowest in the group of 24 months FCA, and was highest in the group of 27 months FCA (p < .05). The percentage of cows culled due to laminitis was lowest in the group of 24 months FCA, and was highest in the group of 28 months or older FCA (p < .05). Displaced abomasum as culling reason was highest in the group of 27 months FCA, and was lowest in the group of 28 months or older FCA (p < .05). The percentage of cows culled because of low milk yield, hepato-gastric problems, udder and the reasons was indifferent among the groups (p > .05).

**Discussion**

**First calving age**

Robotic milking is a new environment for dairy cows, so it is important to re-evaluate the optimum reproduction parameters of cows in this system. We proposed that the results of this study would help the farmers to re-programme their dairy cows’ agenda. In the current study, the milk yield in the first, second, third, and fourth lactation did not differ among the groups. However, the highest average milk yield within the first four lactations was in the group of 24 months FCA. Previous studies have various results in terms of the best FCA to get the highest milk yield. Nilforooshan and Edriss (2004) found that the optimum FCA in terms of milk yield and productive life in Holstein cows was between 21 and 24 months of age. Even though the FCA in the US in the 1980s was 22.5–23.5 (Heinrichs et al. 1994), Ettema and Santos (2004) concluded that FCA less than 23 months of age has a negative effect on milk yield in a Holstein cow herd in California. Do et al. (2013) concluded in a
retrospective study in Korea that the optimum FCA should be between 22.5 and 23.5 in Holsteins in order to get maximum profit. Teke and Murat (2013) conducted a retrospective study in Turkey and found that the optimum FCA for Holstein cows was 23 months for maximum lifetime milk yield. Sawa et al. (2019) concluded that the optimum FCA in Holstein-Friesian cows regarding first lactation milk yield in, lifetime milk production, and longevity is between 22.1 and 26.0 months of age. Shindarska et al. (2016) found that 24 months as an FCA was the best age in terms of milk production compared to those who had their first calving at an older age. Similarly, Haworth et al. (2008) cows of 2.5-year-old and higher FCA had a lower milk yield than those who had a lower FCA. There are various optimum FCA results in previous studies. However, it can be said according to the data of our study that the best FCA to get the highest milk yield in robotic milking farms is 24 months.

**Service period**

The reproductive performance of cows is affected by genetics and environmental factor. However, the heritability of reproductive parameters is very low (Veerkamp et al. 2001; Abdallah and McDaniel, 2000). Milk production has a negative effect on reproductive parameters (De Vries and Risco 2005). Nevertheless, some studies found that the negative effect of milk production on reproductive traits can be compensated by management practices (García-Ispierto et al. 2007). Ansari-Lari et al. (2010) conducted a study on Holstein dairy cows in Iran and found the average service period as 134 days. Furthermore, the same study concluded that the fertility parameters were worsened by increased milk yield. Chagas et al. (2007) also found a negative correlation between milk yield and reproductive performance in dairy cows. Abdallah and McDaniel (2000) conducted a study on Holstein cows and found the average service period as 143 days. Silva et al. (1992) found the average service period was 123 days. Özökök and Feyzi (2007) found that while the effect of breed on service period was insignificant; season, year and parity had a significant effect on the service period. The average service period was found as 125 days in Holstein cows in the same study. The service period in the group of 24 months FCA was among the shortest group (141 days) in our study. There was no significant difference in terms of service period in the second, third, and fourth lactations. This data also supports the hypothesis that having the FCA at 24 months is appropriate in a robotic milking system. On the other hand, there are not enough studies about the optimum reproductive parameters of dairy cows in robotic milking systems, so an objective comparison could not be performed.

**Insemination per conception**

Insemination per conception is an important reproduction parameter that affects the profitability of dairy cows. Heat stress, sperm characteristics, oocyte quality may affect the fertility rate (Walsh et al. 2011). Chebel et al. (2004) found that conception rate was affected by heat stress prior to artificial insemination, parity, diseases after calving. Inchaisri et al. (2010) analysed the economic losses due to reproductive performance and classified the 1.61 number insemination per pregnancy as average. Number of inseminations per pregnancy in each lactation did not significantly differ among all groups. The average number of inseminations per pregnancy in our study differed between 1.62 and 2.21 among all groups. Nevertheless, the highest number of lactations of each group stayed in the herd was in the group of 26 months FCA.

**Culling**

Culling means removing a cow from the herd because of many reasons such as health problems, low milk yield, etc. Culling rate is also another important economic parameter of dairy cattle farms (Fetrow et al. 2006). Culling can also be a tool to speed up the genetic improvement of the herd. Therefore, voluntary culling should be higher in order to improve economic benefits (Weigel et al. 2003). The highest milk yield in dairy cows is achieved after the third lactation (Vijayakumar et al. 2017). That is why culling cows earlier than the third lactation is undesirable. The average culling rate in Estonian dairy cows was 26% per year between the years 2013 and 2015 (Rilanto et al. 2020). The main culling reasons in the same study were feet disorders, udder problems, metabolic and digestive disorders and fertility issues. The average culling rate in the US was 33.0% in 1993, and 31.6% in 1999 (Hadley et al. 2006). Haine et al. (2017) analysed the data between the year 2001 and 2010 of Quebec, Canada and found an average culling rate of 32%. Nor et al. (2013) found the average culling rate for slaughter/death 25.4% in the Netherlands between the year 2007 – 2010. Cumulative culling rate, in the current study, after the second lactation was lowest in the groups of 26 months (52.4%) FCA. The same value was 62.3% in the group of 24 months FCA. In terms of
culling reasons except for age, the rate of mastitis in the 24 months FCA was similar to 25 and 26 months FCA. Furthermore, the rate of reproduction problems as culling reason was lowest in the group of 24 months FCA. Laminitis had also a low rate as a reason of culling in the group of 24 months FCA. Displaced abomasum as a reason of culling had the lowest rate in the group of 24 months FCA.

Conclusions

In general, the results of the present study are consistent with previous research. As a conclusion of the present study, managing the cows to have first calving at 24-months-old had no negative effect in terms of milk yield, service period, number of inseminations per lactation, culling reasons except age criteria. The only negative effect of having the cows to have first calving at the age of 24 months was the “number of lactations of each group stayed in the herd.” This is probably the result of advancements in dairy cattle breeding in recent years. These results suggest that dairy producers using robotic milking can have their cows to be 24-month-old at first calving. However, they have to pay more attention to improving the longevity of their cows in order to improve profitability in the new milking system. Future studies should be done with a greater number of cows and at different farms with different milking systems to have an objective comparison.

Acknowledgements

Authors thank to Yucel Ekici (DVM) his valuable support and participation in the study and Ilhanlar, Sahdem, Ozsaygin and Vurallar Dairy Farms managers for providing access to the data.

Disclosure statement

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article.

ORCID

Gürkan İlhan http://orcid.org/0000-0002-9535-4244
Enver Çavuşoğlu http://orcid.org/0000-0002-9018-3511
Abdulkadir Orman http://orcid.org/0000-0001-9138-4422

References

Abdallah JM, McDaniel BT. 2000. Genetic parameters and trends of milk, fat, days open, and body weight after calving in North Carolina experimental herds. J Dairy Sci. 83(6):1364–1370.

Ansari-Lari M, Kafi M, Sokhtanlo M, Ahmadi HN. 2010. Reproductive performance of Holstein dairy cows in Iran. Trop Anim Health Prod. 42(6):1277–1283.

Chebel RC, Santos JE, Reynolds JP, Cerri RL, Juchem SO, Overton M. 2004. Factors affecting conception rate after artificial insemination and pregnancy loss in lactating dairy cows. Anim Reprod Sci. 84(3–4):239–255.

Chagas LM, Bass JJ, Blache D, Burke CR, Kay JK, Lindsay DR, Lucy MC, Martin GB, Meier S, Rhodes FM, et al. 2007. Invited review: new perspectives on the roles of nutrition and metabolic priorities in the subtlety of high-producing dairy cows. J Dairy Sci. 90(9):4022–4032.

De Koning K, Slaghuis B, Van Der Vorst Y. 2003. Robotic milking and milk quality: effects on bacterial counts, somatic cell counts, freezing point and free fatty acids. Ital J Anim Sci. 2(4):291–299.

De Vries A, Risco CA. 2005. Trends and seasonality of reproductive performance in Florida and Georgia dairy herds from 1976 to 2002. J Dairy Sci. 88(9):3155–3165.

Do C, Wasana N, Cho K, Choi Y, Choi T, Byungho P, Donghee L. 2013. The effect of age at first calving and calving interval on productive life and lifetime profit in Korean Holsteins. Asian-Australas J Anim Sci. 26(11):1511–1517.

Ducrocq V, Quaas RL, Pollak EJ, Casella G. 1988. Length of productive life of dairy cows. 2. Variance component estimation and sire evaluation. J Dairy Sci. 71(11):3071–3079.

Erdman RA, Varner M. 1995. Fixed yield responses to increased milking frequency. J Dairy Sci. 78(5):1199–1203.

Ettema JF, Santos JEP. 2004. Impact of age at calving on lactation, reproduction, health, and income in first-parity Holsteins on commercial farms. J Dairy Sci. 87(8):2730–2742.

Fetrow J, Nordlund KV, Norman HD. 2006. Invited review: culling: nomenclature, definitions, and recommendations. J Dairy Sci. 89(6):1896–1905.

Gabler MT, Tozer PR, Heinrichs AJ. 2000. Development of a cost analysis spreadsheet for calculating the costs to raise a replacement dairy heifer. J Dairy Sci. 83(5):1104–1109.

García-Ispierto I, López-Gatius F, Santolariá P, Yániz JL, Nogareda C, López-Béjar M. 2007. Factors affecting the fertility of high producing dairy herds in northeastern Spain. Theriogenology. 67(3):632–638.

Hadley GL, Wolf CA, Harsh SB. 2006. Dairy cattle culling patterns, explanations, and implications. J Dairy Sci. 89(6):2286–2296.

Haine D, Delgado H, Cue R, Sewalem A, Wade K, Lacroix R, Lefebvre D, Arsenault J, Bouchard E, Dubuc J. 2017. Culling from the herd’s perspective-exploring herd-level management factors and culling rates in Québec dairy herds. Prev Vet Med. 147:132–141.

Hansen BG. 2015. Robotic milking-farmer experiences and adoption rate in Jaeren. Norway J Rural Stud. 41:109–117.

Haworth GM, Tranter WP, Chuck JN, Cheng Z, Wattes DC. 2008. Relationships between age at first calving and first lactation milk yield, and lifetime productivity and longevity in dairy cows. Vet Rec. 162(20):643–647.

Heinrichs AJ, Wells SJ, Hurd HS, Hill GW, Dargatz DA. 1994. The national dairy heifer evaluation project: a profile of
heifer management practices in the United States. J Dairy Sci. 77(6):1548–1555.

Inchaisri C, Jorritsma R, Vos PL, Van der Weijden GC, Hogeveen H. 2010. Economic consequences of reproductive performance in dairy cattle. Theriogenology. 74(5):835–846.

Kruip TAM, Morice H, Robert M, Ouweltjes W. 2002. Robotic milking and its effect on fertility and cell counts. J Dairy Sci. 85(10):2576–2581.

Le Cozler Y, Lollivier V, Lacasse P, Disenhaus C. 2008. Rearing strategy and optimizing first-calving targets in dairy heifers: a review. Animal. 2(9):1393–1404.

Nilforooshan MA, Edriss MA. 2004. Effect of age at first calving on some productive and longevity traits in Iranian Holsteins of the Isfahan province. J Dairy Sci. 87(7):2130–2135.

Nor NM, Steeneveld W, Van Werven T, Mourits MCM, Hogeveen H. 2013. Hogeveen H. First-calving age and first-lactation milk production on Dutch dairy farms. J Dairy Sci. 96(2):981–992.

Oltenacu PA, Broom DM. 2010. The impact of genetic selection for increased milk yield on the welfare of dairy cows. Anim Welf. 19:39–49.

Örs A, Öğuz C. 2018. Economic performance of robotic milking. Manas J. Agric. Vet. Life Sci. 8:35–51.

Özkök H, Feyzi U. 2007. Türkiye’de yetiştirilen Esmer ve Siyah Alaca sığır larda süt verimi, ilk buzağılama yaş ve servis periyodu. Atatürk Üniv Ziraat Fak. Derg. 38:143–149.

Rilanto T, Reimus K, Orro T, Emanuelson U, Viltrop A, Mötus K. 2020. Culling reasons and risk factors in Estonian dairy cows. BMC Vet Res. 16(1):1–16.

Sawa AK, Siatka K, Krężel-Czopek S. 2019. Effect of age at first calving on first lactation milk yield, lifetime milk production and longevity of cows. Ann Anim Sci. 19(1):189–200.

Shindarska Z, Popov G, Ralchev I. 2016. Influence of age at first calving on milk quantity at Holstein-Friesian cows. Int J Curr Microbiol App Sci. 5(3):254–259.

Siewert JM, Salfer JA, Endres MI. 2018. Factors associated with productivity on automatic milking system dairy farms in the Upper Midwest United States. J Dairy Sci. 101(9):8327–8334.

Silva HM, Wilcox CJ, Thatcher WW, Becker RB, Morse D. 1992. Factors affecting days open, gestation length, and calving interval in Florida dairy cattle. J Dairy Sci. 75(1):288–293.

Teke B, Murat H. 2013. Effect of age at first calving on first lactation milk yield, lifetime milk yield and lifetime in Turkish Holsteins of the Mediterranean region in Turkey. Bulg J Agric Sci. 19:1126–1129.

Veerkamp RF, Koenen EPC, De Jong G. 2001. Genetic correlations among body condition score, yield, and fertility in first-parity cows estimated by random regression models. J Dairy Sci. 84(10):2327–2335.

Vijayakumar M, Park JH, Ki KS, Lim DH, Kim SB, Park SM, Jeong HY, Park BY, Kim TI. 2017. The effect of lactation number, stage, length, and milking frequency on milk yield in Korean Holstein dairy cows using automatic milking system. Asian-Australas J Anim Sci. 30(8):1093–1098.

Walsh SW, Williams EJ, Evans ACO. 2011. A review of the causes of poor fertility in high milk producing dairy cows. Anim Reprod Sci. 123(3-4):127–138.

Weigel KA, Palmer RW, Caraviello DZ. 2003. Investigation of factors affecting voluntary and involuntary culling in expanding dairy herds in Wisconsin using survival analysis. J Dairy Sci. 86(4):1482–1486.