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The extent of increase in first calving age as a result of implementing various sexed semen breeding strategies

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Abstract

A deterministic simulation was conducted to assess the effects of sexed semen utilization strategies on age at first calving (AFC). Four different strategies were implemented on dairy heifers: continuous use of conventional semen only (CC), continuous use of sexed semen only (SS), utilization of sexed semen for both the first and second services with conventional semen afterwards (S2), and utilization of sexed semen for the first service with conventional semen afterwards (S1). Results indicated that continuous utilization of sexed semen led to the greatest AFC; however at high conception rates, strategies displayed negligible differences on AFC. Increases in estrus detection rate had the greatest effects on decreasing AFC of the SS scenarios. Negative effect of sexed semen on AFC increased when the effect of low estrus detection rate was combined with low conception rate of sexed semen. Results indicated that in the case of access to sexed semen conception rate, prediction of AFC is possible by quadratic polynomial or exponential equations, depending to the applied breeding strategy. Simultaneous utilization of sexed and conventional semen in a herd did not make a substantial change in AFC when a low percentage of sexed semen was employed. Increasing the contribution of different sexed semen strategies led to higher AFC variation, especially for the SS strategy. AFC of strategies that utilize sexed semen is highly dependent on the conception rate, estrus detection rate and the contribution of sex sorted semen in the total number of inseminations of the heifer herd.

Additional key words: age at first calving; conception rate; estrus detection rate.

Introduction

The beginning of a cow's productive life is marked by age at first calving (AFC). Raising heifers so that they could enter the milking herd at the desired age and weight is the major goal of replacement programs in dairy industry. An optimum AFC is desired because an increase in AFC is associated with heifer rearing expenses and leads to increased generation interval and decreased life production (Mohd Noor *et al.,* 2013). On the other hand, a reduced AFC may cause productive and reproductive problems for heifers (Mohd Nor *et al.,* 2013). The recommended AFC of heifers is about 24 months (Nilforooshan & Edriss, 2004).

Flow cytometry is the most common procedure for separating bovine sperm bearing X *vs.* Y chromosomes (Seidel & Garner, 2002; Weigel, 2004). Since the early 21st century, utilization of this technology has been commercialized for producing sexed semen in cattle (Cassell, 2005; DeJarnette, 2005; DeJarnette *et al.*, 2009). The reliability of separating males *vs.* female sperm by flow cytometer varies among different sires at a range from 85 to 95% (Garner & Seidel, 2003).

Altering the sex ratio by semen sexing is a great advantage in the supply of replacement heifers (Moore & Tatcher, 2006; De Vries *et al.,* 2008). The use of sexed semen has the possibility to improve herd turnover rates and to decrease the risk of diseases associated

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Abbreviations used: AFC (age at first calving); CC (continuous utilization of conventional semen); CPR (cumulative pregnancy rate); CR (conception rate); EDR (estrus detection rate); PR (pregnancy rate); S1 (the use of sexed semen at the first service and the use of conventional semen for the remaining services); S2 (the use of sexed semen at the first and the second service and the use of conventional semen for the remaining services); SPC (number of services per conception); SS (continuous utilization of sexed semen).

with purchased animals (De Vries *et al.,* 2008). In addition, less dystocia (Fetrow *et al.,* 2007) and increased genetic progress by up to 15% (Hohenboken, 1999; Weigel, 2004) is expected when utilizing this kind of semen.

The conception rate of sexed semen has been reported to be lower than that of conventional semen. For instance Seidel & Schenk (2002) reported a conception rate of 31 to 42% for sexed semen compared to a conception rate of 43 to 62% for conventional semen in Holstein and Jersey heifers in three different states in the USA. Garner & Seidel (2003) reported a conception rate of 30% for sexed semen compared to a 50% conception rate for conventional semen. Weigel (2004) reported a conception rate of 58% when heifers were bred to conventional semen and a conception rate of 21-37% when heifers were bred to sexed semen. On the other hand, Andersson *et al.* (2006) found conception rates of 46% and 21% in lactating cows when they were bred to conventional and sexed semen, respectively. In a comprehensive study in the USA, Norman *et al.* (2010) reported a 56% conception rate for conventional semen versus a 39% conception rate for sexed semen in Holstein heifers. DeJarnette *et al.* (2011) found a conception rate of 38% and 44% for sexed semen and 55% and 60% for conventional semen, for $2.1 \cdot 10^6$ and $10 \cdot 10^6$ sperm dosages, respectively. Frijters *et al.* (2009) and DeJarnette *et al.* (2011) explained that it is not sperm dosage but the sex-sorting procedure that has the most impact on conception rate of sexed semen. According to the reported conception rates in these and the other studies (*i.e.* Bodmer *et al.*, 2005; Borchersen & Peacock, 2009; Chebel *et al.*, 2010) it can be concluded that the conception rates of sexed semen are about 40 to 78% of those of conventional semen.

In spite of its ability to produce near 90% female offspring (Seidel & Schenk, 2002; Seidel, 2003; DeJarnette *et al.*, 2009) the use of sex-sorted semen has been primarily limited to virgin heifers as they are subject to higher conception rates (Seidel, 2007; DeJarnette *et al.*, 2009). DeJarnette *et al.* (2009) reported that conception rates of sexed semen in the first, the second, and the third + services averaged 47, 39, and 32% for heifers and 26, 30 and 27% for lactating cows, respectively.

Conception rates of the first and the second services of heifers was reported by DeJarnette *et al.* (2011) to be 54% and 45%, respectively. The variation in conception rates of the second service compared to the first service is related to the sire's genetic value of conception rate. For this reason it is possible to find various conception rates for the second inseminations of heifers from a specific sire (Borchersen & Peacock, 2009; Chebel *et al.*, 2010).

The lower conception rate of sexed semen could have several genetic impacts, including a change in first calving age of heifers and an increase in the calving interval of lactating cows (Chebel *et al.*, 2010). Generation interval is directly dependent on the AFC. Hence, an increase in AFC could reduce genetic progress as a result of an increase in the generation interval. Earlier insemination of dairy heifers with sexed semen has been proposed for reducing the impact of lower conception rate of sexed semen on AFC (Weigel, 2004). Furthermore, it has also been proposed that heifers should only be inseminated with sexed semen for the first service and subsequently with conventional semen when they do not conceive. Chebel *et al.* (2010) found that by inseminating heifers with sexed semen at a slightly younger age there was not a significant difference in AFC among heifers who had been impregnated by sexed or conventional semen. In spite of its effect on decreasing AFC it is not recommended to inseminate heifers at very young age due to the poor productive and economic performance of heifers that calve less than 23 months (Ettema & Santos, 2004; Chebel *et al.*, 2010). Production merit and life time profit of replacement heifers are maximized if heifers are inseminated by 14-16 months of age (Fricke, 2004).

While the AFC is affected by differing conception rates, it can also be impacted by the estrus detection rate. Different values of the estrus detection rate in cows and heifers have been reported ranging from 30 to 90% (Plaizier *et al.*, 1997; Richardson *et al.*, 2002).

To our knowledge, there is no comprehensive study that documents the change in AFC when breeding schemes that utilize a mixture of sexed and conventional semen are used. The objective of the current study was therefore to document the impact of conception rates of sexed semen on the AFC in various breeding schemes

Material and methods

Base scenarios

A deterministic approach was employed to investigate the AFC under various breeding strategies based on a combined use of sexed and conventional semen. The conception rate of dairy heifers when inseminated with sexed semen was assumed to be 70% of that achievable with conventional semen. Virgin heifer conception rate for conventional sperm was set to 56%. The sex ratio of conventional semen was set at 49.2% female and 50.8% male (Ryan & Boland, 1991). The accuracy of semen sorting and hence the sex ratio resulting from utilizing sexed semen was set to 90% female and 10% male (Seidel & Schenk, 2002). Estrus detection rate (EDR) was set at 80%.

To find the effect of the use of sexed semen on AFC, several breeding strategies similar to those proposed by Olynk & Wolf (2007) were evaluated: SS, continuous use of sexed; S1, use of sexed semen for the first service followed by conventional semen for the second to the last service; S2, use of sexed semen for the first and second services and the use of conventional semen for the remained services; and CC, continuous use of conventional semen (control strategy).

Pregnancy rate (PR) was defined as the product of conception rate (CR) and estrus detection rate. For subsequent services, pregnancy rate was obtained as follows:

$$\left.\begin{array}{l} PR_i = CR \times EDR = PR \\ CPR_i = PR \end{array}\right\} \text{for } i = 1$$

$$\left.\begin{array}{l} PR_i = (1 - CPR_{i-1}) \times PR \\ CPR_i = CPR_{i-1} + (1 - CPR_{i-1}) \times PR \end{array}\right\} \text{for } i = 1,2,3,\ldots,SPC$$

CPR_i is the cumulative pregnancy rate after the *i*th service. The number of necessary services per conception (*SPC*) for each scenario was set once for reaching to a minimum CPR of 90% and once for achieving a maximum of four services. Heifers that did not conceive under these limitations were culled from population. The number of SPC was limited to 4 because it is a common practice in Iran to cull heifers that do not conceive after the 4th or 5th service.

Age at first calving at each service (AFC_i) was computed considering number of SPC, and by including the first insemination age (14 months of age), estrus length (21 days) and gestation length (which was obtained as the weighted mean of the length of gestation for an average calf). Mean gestation length was calculated considering the probability of a male or female calf of each semen type multiplied by the gestation length of the relevant sex. Gestation length for pregnancies with conventional semen was set at 272 d for female calves and 273 d for male calves. Gestation length for pregnancies from sexed semen was set at 274 and 275 d for the female and male calves, respectively. Finally, the AFC was obtained for each strategy as follows:

$$AFC = \frac{\sum_{i=1}^{SPC} AFC_i \cdot PR_i}{CPR_{SPC}}$$

Alternative scenarios

Change in conception rate

Considering various conception rates reported for sexed *vs.* conventional semen, the proportion of the conception rate of conventional semen obtained with sexed semen was changed from 40 to 90% (1% interval). It was assumed that the conception rate of conventional semen varied from 50 to 90% (1% interval). A number of 2091 different scenarios were investigated for strategies SS, S1 and S2, and 41 different scenarios were set for the CC strategy.

The average AFC was obtained for each strategy twice; once for reaching a minimum CPR of 90%, and once by limiting number of SPC to a maximum value of 4. Finally, different strategies were compared by their effect on AFC.

Change in estrus detection rate

Different estrus detection and heat synchronization programs in different herds lead to various rates of estrus detection. Hence, EDR was manipulated to see how it affected AFC. Strategies described for the base scenarios were employed. The value of conception rate for conventional and sexed semen was fixed at 56% and 39% respectively. The EDR varied from 50 to 100% (1% interval) to demonstrate its effect on the average AFC.

Concurrent change in conception rate and estrus detection rate

At this stage, conception rate and estrus detection rate were changed simultaneously to determine their effect on AFC. The range of change in conception rate of conventional semen, the proportion of the conception rate of conventional semen obtained with sexed semen and estrus detection rate were changed similar to their values in the previous sections. Hence, 106,641 different scenarios were simulated for each strategy.

Change in percent of heifers that are subject to sexed sperm

In the previous scenarios, it was assumed that sexed semen was utilized on all heifers. In reality only a small part of the herd was subject to sexed semen. For this reason, the study endeavored to find out if there is an optimum rate for utilizing sex sorted semen with regard to its effect on AFC.

The base scenario was again employed with conception rates of conventional and sexed semen that were fixed at 56% and 39% respectively. Pure and mixed sexed semen breeding strategies (SS, S2 and S1) were applied for 0 to 100% (1% interval) of heifers. The remaining heifers were serviced with only conventional semen. Finally, average AFC was obtained via the weighted mean of AFC resulting from the various uses of conventional and sexed semen.

All calculations were performed in Matlab 7.0.4. SigmaPlot 12 was utilized to draw 3D plots and counter plots of changes in AFC for various scenarios over each strategy.

Results

Base scenario

Under the base scenario, the number of SPC necessary to achieve a 90% CPR ranged from 4 to 7 among different strategies (Table 1). The CC strategy led to the lowest AFC; while the SS strategy led to the greatest AFC. Mixed use of conventional and sexed sorted semen (strategies S1 and S2) resulted in intermediate values of AFC. As expected, AFC was greater for the strategy S2 compared to strategy S1.

Table 1. Service per conception (SPC), cumulative pregnancy rate (CPR) and expected age at first calving (AFC) resulting from pure and mixed sexed semen breeding strategies in the base scenario

Limitations[1]	Strategy[2]	SPC	CPR	AFC (days)
$MIN_{CPR} = 0.90$	SS	7	0.93	734.53
	S2	5	0.92	727.63
	S1	5	0.94	724.33
	CC	4	0.91	715.62
$SPC_{max} = 4$	SS	4	0.78	721.93
	S2	4	0.86	723.52
	S1	4	0.88	720.94

[1] MIN_{CPR}: minimum cumulative pregnancy rate which has been set to 90%; SPC_{max}: maximum number of SPC which has been set to 4. [2]SS: continuous usage of sexed semen; S2: use of sexed semen for the 1st and the 2nd inseminations followed by conventional semen; S1: use of sexed semen at the 1st inseminations followed by conventional semen; CC: continuous utilization of conventional semen.

When limiting the number of SPC to 4 services, the average AFC decreased from 734.53 d to 721.93 d in the SS strategy. The CPR was decreased by 15% (from 93 to 78%). Similarly, AFC of the S2 and S1 strategies decreased by 4.11 and 3.39 d. The order of AFC between the different strategies was also changed. When limiting number of services to 4, the AFC of the S2 strategy was greater than that of SS strategy due to a higher proportion of heifers conceiving under S2 strategy (CPR = 0.86) compared to the SS strategy (CPR = 0.78). Lower AFC after the continuous use of sexed semen strategy resulted from lower pregnancy rate in the 3rd and 4th services (15 and 10%) in contrast with S2 strategy (21% and 12% pregnancy rate at 3rd and 4th services).

Alternative scenarios

Change in conception rate

The impacts of simultaneous change of conventional semen conception rate and the sexed semen conception rate on number of SPC, CPR and AFC are summarized in Table 2. The conception rate of sexed semen ranged from 20% to 81% depending on the conception rate of conventional semen and the proportion of the conception rate of sexed to conventional semen. When limiting the scenarios to a minimum CPR of 90%, the greatest number of SPC was obtained under the SS strategy (number of services = 14) and the lowest number was reached under the CC and S1 strategies (number of services = 2). The average number of SPC was 6.14, 4.31, 3.86 and 3.41 for the SS, S2, S1 and CC strategies, respectively.

The greatest and the lowest AFC was obtained under SS (782.14 d) and CC (710.66 d) strategies, respectively. The average AFC was 730.21 d for the SS strategy and 723.54, 718.52 and 710.66 d for S2, S1 and CC strategies, respectively. AFC declined due to an increase in conception rate of sexed and conventional semen. The trends of AFC over different strategies and under different pregnancy rates were consistent with changes in the number of SPC.

The greatest and the smallest CPR were 97% and 90%, respectively. The SS strategy showed the lowest

Table 2. Average service per conception (SPC), cumulative pregnancy rate (CPR) and expected age at first calving (AFC) resulting from various breeding strategies in a variable rate of conception of sex sorted semen and different proportion of sexed *versus* conventional semen*

Condition[1]	Strategy[2]	SPC			CPR			AFC (days)		
		Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
$MIN_{CPR} = 0.90$	SS	6.14	3	14	0.91	0.90	0.96	730.21	708.47	782.14
	S2	4.31	3	6	0.93	0.90	0.97	723.54	708.63	743.19
	S1	3.86	2	6	0.93	0.90	0.97	718.52	705.39	734.79
	CC	3.41	2	5	0.93	0.90	0.97	710.66	702.94	720.99
$SPC_{max} = 4$	SS	3.93	3	4	0.81	0.50	0.96	719.95	708.47	726.90
	S2	3.83	3	4	0.90	0.75	0.97	721.58	708.63	732.95
	S1	3.61	2	4	0.92	0.82	0.97	717.60	705.39	726.93
	CC	3.29	2	4	0.93	0.87	0.97	710.25	702.94	717.33

[1] MIN_{CPR}: minimum cumulative pregnancy rate which has been set to 90%; SPC_{max}: maximum number of SPC which has been set to 4. [2] 2SS: pure continuous usage of sexed semen; S2: the use of sexed semen for the 1st and the 2nd inseminations followed by conventional semen; S1: the use of sexed semen at the 1st inseminations followed by conventional semen; CC: pure continuous utilization of conventional semen.

CPR average (91%) while similar averages of CPR were obtained under the S1, S2 and CC strategies (93%). Mean CPR of the SS strategy was decreased by 10% after limiting the number of SPC over different scenarios. Furthermore, the average CPR of the S1 and S2 strategies showed a slight decrease (3% and 1% respectively) after this limitation. The average AFC was decreased in scenarios applying a maximum number of services of 4 compared to those applying a minimum CPR of 90%. This decline was greater under the SS strategy (10.26 d) compared to the S2 (1.96 d), S1 (7.86 d) and CC (0.41 d) strategies. The minimum AFC of different strategies was constant while limiting the number of SPC. Change in average AFC due to this limitation was a result of the change under scenarios with low pregnancy rates and large number of SPC. Limiting the number of services to 4 services decreased the average number of SPC over different strategies, especially for the strategy SS. Setting the scenarios to reach a maximum number of services of 4 led to lower mean AFC and a lower average of number of SPCs. Such a change could decrease profitability of the herd due to a decline in CPR.

When continuous use of sexed semen, AFC was considerably greater at low conception rates. An increase in pregnancy rate of sexed semen led to a similar AFC in different strategies. On the other hand, for some pregnancy rates, the S2 strategy led to lower AFC compared to strategy S1, which is related to the conception rate of sexed versus conventional semen. This means that if the proportion of conception rate of conventional semen obtained by sexed semen is considerably high, it could lead to a desirable decrease in the AFC.

Investigation of the differences in AFC of the various strategies from their related values in strategy CC at different conception rates of sexed *versus* conventional semen, showed that the SS strategy led to the greatest and S1 led to the lowest AFC differences. Higher proportions of conception rate of sexed versus conventional semen considerably decreased the AFC differences, especially for the SS strategy. None of the strategies involving sexed semen can lead to AFC similar to that achievable with strategy CC. At a proportion of 85% or more, the AFC differences among the sexed semen strategies were similar to each other. While at realistic proportions (like 70%), any combination of sexed and conventional semen strategies had more similar AFC differences compared to SS.

Trend line equations (with the largest R^2), fitted for the AFC as a result of changes in the conception rate of sexed semen in various strategies and over different conditions are presented in Table 3. When limiting the minimum CPR to 90%, a quadratic polynomial equation presented the best fit for the SS strategy while an exponential equation suited better for S2 and S1 strategies. On the other hand, when limiting the number of services to 4, all the strategies were well fitted by quadratic polynomial equations. In both situations, the greatest R^2 was obtained for the SS strategy. Hence, it is possible to predict the AFC of various strategies, if we have access to the real value of the conception rate with sexed semen.

Table 3. Trend line equation of various pure and mixed sexed semen strategies for predicting age at first calving (y) as a result of change in sexed semen conception rate (x)

Condition[1]	Strategy[2]	Trendline equation	Trend type	R^2
$MIN_{CPR} = 0.90$	SS	$y = 225.93x^2 - 319.3x + 824.91$	Polynomial	0.9837
	S2	$y = 702.37x^{-0.036}$	Exponential	0.9629
	S1	$y = 703.94x^{-0.025}$	Exponential	0.8203
$SPC_{max} = 4$	SS	$y = -21.464x^2 - 9.9016x + 729.26$	Polynomial	0.9901
	S2	$y = 4.7357x^2 - 47.495x + 742.13$	Polynomial	0.9823
	S1	$y = 13.551x^2 - 45.619x + 735.32$	Polynomial	0.8844

[1] MIN_{CPR}: minimum cumulative pregnancy rate which has been set to 90%; SPC_{max}: maximum number of SPC which has been set to 4. [2] SS: pure continuous usage of sexed semen; S2: the use of sexed semen for the 1st and the 2nd inseminations followed by conventional semen; S1: the use of sexed semen at the 1st inseminations followed by conventional semen.

Change in estrus detection rate

The effects of different estrus detection rates on the number of SPC, CPR, and AFC are presented in Table 4. When limiting the scenarios to reach a minimum CPR of 90%, the largest number of SPC was reached under the SS strategy (number of services = 11) and its lowest number was obtained under the CC strategy (number of services = 2). The average number of services was 7.43, 5.31, 5.65 and 4.94 for SS, S1, S2 and CC strategies, respectively.

The greatest and the lowest AFC was obtained under the SS (763.02 d) and CC (708.97 d) strategies. The average AFC was 738.81, 731.80, 727.36 and 720.62 d for SS, S2, S1 and CC strategies, respectively. Increases in estrus detection rate decreased AFC. The trends in AFC in different estrus detection rate was consistent with the changes in number of SPC. The quadratic polynomial equations showed the largest R^2 when predicting the AFC due to changes in estrus detection rate (results are not shown).

The greatest and the lowest CPR was 95% and 90%, respectively. Similar mean CPRs were obtained under different strategies (92%). The mean CPR decreased differently after limiting scenarios to reach a maximum number of services of 4 (18, 10, 7 and 4% decrease for SS, S2, S1 and CC strategies, respectively). The average AFC decreased in scenarios with a maximum services of 4 compared to scenarios with a minimum CPR of 90%. Mean AFC was 722.56, 724.24, 721.73 and 716.32 d for SS, S2, S1 and CC strategies, respectively. Limiting number of services to 4 decreased the average number of services in various strategies, especially for SS.

At larger estrus detection rates, there were slight differences in AFC of various strategies while the differences increased at lower estrus detection rates. At a specific estrus detection rate, AFC of S1 and S2 stra-

Table 4. Average service per conception (SPC), cumulative pregnancy rate (CPR) and expected age at first calving (AFC) resulting from various breeding strategies in at different estrus detection rate

Condition[1]	Strategy[2]	SPC			CPR			AFC (days)		
		Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
$MIN_{CPR} = 0.90$	SS	7.43	5	11	0.92	0.90	0.94	738.81	722.99	763.02
	S2	5.65	4	8	0.92	0.90	0.95	731.80	720.36	748.82
	S1	5.31	4	8	0.92	0.90	0.95	727.36	717.56	744.80
	CC	4.94	3	8	0.92	0.90	0.95	720.62	708.97	739.26
$SPC_{max} = 4$	SS	4	4	4	0.74	0.58	0.86	722.56	719.21	725.78
	S2	4	4	4	0.82	0.66	0.93	724.24	720.36	727.95
	S1	4	4	4	0.85	0.70	0.95	721.73	717.56	725.77
	CC	3.91	3	4	0.88	0.73	0.95	716.32	708.97	721.47

[1] MIN_{CPR}: minimum cumulative pregnancy rate which has been set to 90%; SPC_{max}: maximum number of SPC which has been set to 4. [2]SS: pure continuous usage of sexed semen; S2: the use of sexed semen for the 1st and the 2nd inseminations followed by conventional semen; S1: the use of sexed semen at the 1st inseminations followed by conventional semen; CC: pure continuous utilization of conventional semen.

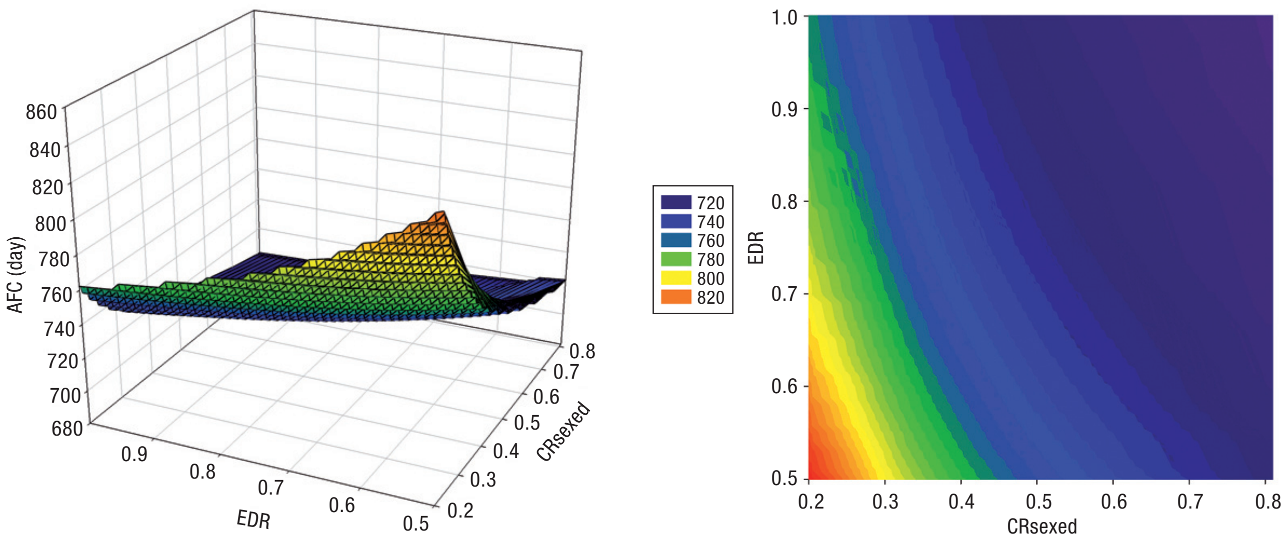

Figure 1. Counter plot and 3D plot of the change in the age at first calving age (AFC) as a result of changes in conception rate of sexed semen (CRsexed) and estrus detection rate (EDR) in SS strategy (continues use of sexed semen for heifers).

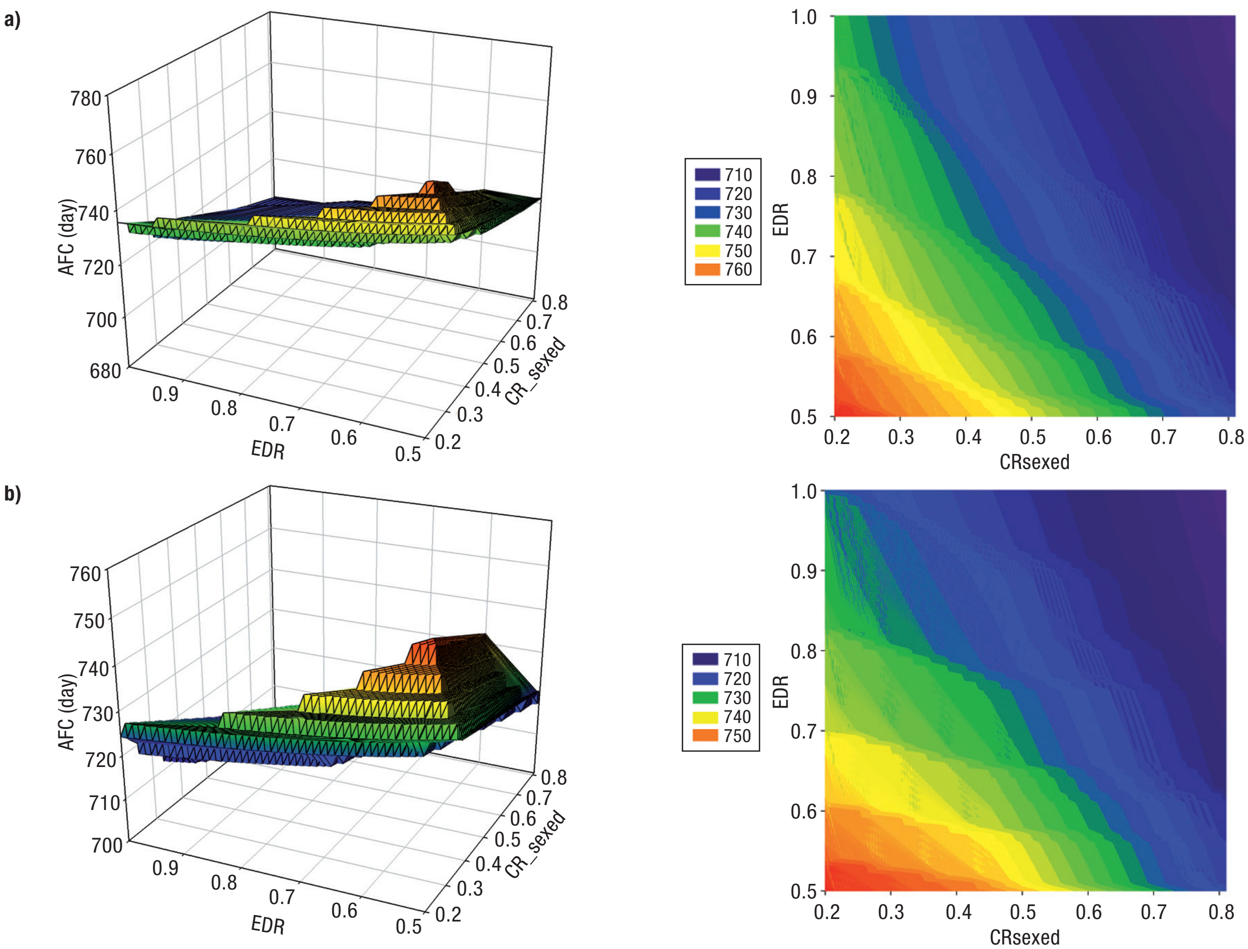

Figure 2. Counter plot and 3D plot of the change in the first calving age (AFC) as a result of change in conception rate of sexed semen (CRsexed) and estrus detection rate (EDR) in (a): S2 strategy, use of sexed semen for the first and the second services of heifers with conventional semen afterwards, and (b): S1 strategy, use of sexed semen for the first services of heifers with conventional semen afterwards.

tegies were more similar if the related scenarios had the same number of SPC.

Concurrent change in conception rate and estrus detection rate

Plots 3D and their related counter plots showing changes in AFC by simultaneous change in sexed semen conception rate (the product of conventional semen conception rate and the proportion of the conception rate of sexed *versus* conventional semen) and estrus detection rate (limiting CPR to 90%) are presented in Figs. 1 and 2. The change in AFC of the SS strategy had a more systematic trend compared to other strategies. On the other hand, counter plots revealed that the SS strategy led to a larger AFC compared to the other strategies. The extent of change in the AFC in various strategies are presented in Fig. 3. Although the minimum AFC was similar for different strategies, their maximums were more variable. The greatest age AFC was obtained in the SS strategy (AFC = 838.47 d), when estrus detection rate and conception rate of sexed semen had their smallest value. By limiting strategies to at most 4 services, we found that the maximum age AFC was obtained in the S2 strategy. Different CPRs after limiting the number of SPC was the reason for a different order of strategies for AFC. Equations fitted for predicting the AFC considering all effective parameters (*i.e.* conception rate of conventional semen, the rate of conception rate of sexed *versus* conventional semen and estrus detection rate) are presented in Table 5.

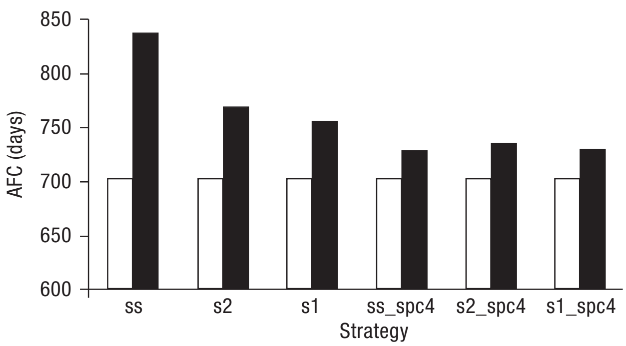

Figure 3. Minimum and maximum value of age at first calving (AFC) in various pure and mixed sexed semen strategies by simultaneous change in conception rate and estrus detection rate. SS: continues use of sexed semen for heifers; S2: the use of sexed semen for the first and the second services of heifers with conventional semen afterwards; S1: the use of sexed semen for the first service of heifers with conventional semen afterwards; spc4: limitation of number of services per conception to 4 services.

All the strategies were equitably fitted to a first order multivariate equation (adjusted R^2 was greater than 90%). Hence it is possible to predict AFC with a reasonable accuracy.

Change in percent of heifers that are subject to sexed semen

The effects of change in the use of sex sorted semen on number of SPC, CPR and AFC for different employed strategies are presented in Table 6.

As expected, the average number of services and hence mean AFC was low because only a small part of the heifers were subjected to insemination with sexed semen. The maximum number of services resulted from the SS strategy (number of services = 7) while its minimum value was the same for all strategies. The largest average number of services was obtained under the SS strategy (5.38). Mean AFC decreased after limiting the strategies to a maximum services of 4. The greatest and the lowest decrease in AFC was obtained for the SS (5.39 d) and S1 (2.21 d) strategies, respectively.

When the use of sex sorted semen in herd was low (less than 10%), AFC was similar over different strategies. When more sexed semen was used, the AFC of the SS strategy was increased rapidly and consistently with a rise in the number of services. Utilization of sexed semen by 15 to near 60% of the heifers led to similar AFC under SS and S2 strategies. Utilization of sexed semen above 60% increased the difference in AFC of SS and S2 strategies.

Discussion

The results showed that the utilization of any sexed semen strategy increased the AFC. The larger AFC of the strategies based on sexed semen was mainly correlated to their larger number of SPC resulting from this kind of semen. Despite the slight effect of gestation length on AFC in our study, in trials it has been confirmed that sex sorted semen does not have a significant effect on gestation length (Tubman *et al.,* 2004). Although an increase in AFC could improve average milk components of dairy herds, it has been stated that a medium AFC is favorable due to its effect on declining the incidence of mastitis and lameness, and improved herd economic return (Ettema & Santos, 2004). If we suppose that 700-750 d is an optimum range for the AFC, it

Table 5. Adjusted equations for predicting first calving age at different conditions and over various strategies*

Condition[1]	Strategy[2]	Equation[3]	Adjusted R^2
$MIN_{CPR} = 0.90$	SS	AFC = 896.18 – 75.84x – 83.32y – 71.39z	0.92
	S2	AFC = 820.5 – 49.19x – 37.03y – 46.29z	0.96
	S1	AFC = 799.18 – 45.81x – 20.03y – 43.21z	0.95
$SPC_{max} = 4$	SS	AFC = 758.72 – 18.21x – 19.37y – 16.90z	0.92
	S2	AFC = 773.62 – 23.01x – 29.23y – 21.32z	0.96
	S1	AFC = 766.05 – 25.68x – 17.63y – 23.94z	0.96

[1] MIN_{CPR}: minimum cumulative pregnancy rate which has been set to 90%; SPC_{max}: maximum number of SPC which has been set to 4. [2] SS: pure continuous usage of sexed semen; S2: the use of sexed semen for the 1st and the 2nd inseminations followed by conventional semen; S1: the use of sexed semen at the 1st inseminations followed by conventional semen; CC: pure continuous utilization of conventional semen. [3] x: conception rate of conventional semen, y:conception rate of sexed *versus* conventional semen, z: estrus detection rate.

could be concluded that in most of the investigated strategies, the optimum value of AFC was obtained. However, when conception rate or estrus detection rate were changed separately, the optimum AFC was exceeded in the SS strategy. By concurrent change of the conception rate and estrus detection rate, all strategies tended to exceed the optimum AFC in some of their scenarios. However, by limiting the number of services to 4, the AFC of those scenarios was decreased to the optimum range. Although the AFC was optimum in most scenarios, their value was obtained under a minimum first insemination age (14 months). If the first insemination age increases by at least one month, a large number of scenarios exceed the optimum AFC. A minimum first insemination age of 14 months is desired if heifers could reach their standard premature weight. A lower first insemination age would not be advantageous because future milk production is compromised (Mohd Nor *et al.,* 2013). Although by limiting number of SPC, we could reach the optimum AFC, this limitation has to be applied by caution. Because it could cause a lower CPR and a greater number of culled heifers which subsequently increases heifer rearing expenses.

Generation interval which has reverse relation to genetic progress is depended to AFC, calving interval and sex-age classes of herd. Using more sexed semen results in more heifer calves born out of heifers compared to heifer calves born out of cows. In an expanding herd the use of sexed semen reduces the generation interval because of greater number of heifers in the first age class of the herd. While considering a constant herd size, increases in AFC lengthen the generation interval. Hence, strategies like SS have a greater effect on generation interval compared to strategies like S1 and S2 that utilize sexed semen combined with conventional semen. In spite of its positive effect on selection accuracy (Baker *et al.*, 1990) the potential advantage of sexed semen to increase genetic progress in the

Table 6. Average service per conception (SPC), cumulative pregnancy rate (CPR) and expected age at first calving (AFC) resulting from various AI strategies at different rates of sexed sperm usage

Condition[1]	Strategy[2]	SPC			CPR			AFC (days)		
		Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
$MIN_{CPR} = 0.90$	SS	5.38	4	7	0.92	0.90	0.94	724.19	715.62	734.53
	S2	4.84	4	5	0.93	0.90	0.94	722.52	715.62	727.63
	S1	4.68	4	5	0.93	0.90	0.94	720.51	715.62	744.33
$SPC_{max} = 4$	SS	4	4	4	0.85	0.78	0.91	718.80	715.62	721.93
	S2	4	4	4	0.88	0.86	0.91	719.48	715.62	723.52
	S1	4	4	4	0.90	0.88	0.91	718.30	715.62	720.94

[1] MIN_{CPR}: minimum cumulative pregnancy rate which has been set to 90%; SPC_{max}: maximum number of SPC which has been set to 4. [2] SS: pure continuous usage of sexed semen; S2: the use of sexed semen for the 1st and the 2nd inseminations followed by conventional semen; S1: the use of sexed semen at the 1st inseminations followed by conventional semen.

dam pathways is limited due to the lengthening of the generation interval.

Improvements in reproductive technologies resulting in an increase in conception rate of sex sorted semen could lead to a lower AFC results for the different sexed semen AI strategies. It has been shown that conception rates of 20-40% are practically achievable with sex sorted semen (Seidel & Schenk, 2002; Weigel, 2004; Andersson *et al.*, 2006; Norman *et al.*, 2010). Hence, it is expected that under suitable management practices, no significant differences in AFC will be found among different breeding strategies that utilize sexed semen.

Enhancing conception rate of sexed semen is possible by increasing the sperm dosage of sexed semen (DeJarnette *et al.*, 2011). To enrich sperm dosage it is necessary to use more semen and the economic consequences of such increases must be considered. Another way to enhance the conception rate of sexed semen is to use sires whose sperm have more resistance to the semen sorting process. The possibility to evaluate and select different sires for their ability to produce sexed semen with higher conception rates exists if enough information could be gathered.

Estrus detection rate affects pregnancy rate, and is just as important as conception rate. Due to the breeder's effect on estrus detection rate it could be concluded that the success in the use of sexed semen is highly dependent on estrus management practices. Management of artificial insemination of cows must adapt to variations among primi and multiparous cows in: 1) estrus duration, 2) intervals between estrus onset and ovulation, 3) intervals between LH surge and ovulation. Introduction of new reproductive technologies could allow a high estrus detection rate to be reached (Kemmer *et al.,* 2011).

Usually breeders inseminate a small part of their heifers with sexed semen. Hence, simultaneous utilization of sexed and conventional semen is a more realistic case. Despite greater utilization of sexed semen in larger herds, it is usually limited to 10 to 20% of the first parity cows. It is expected that the use of sexed semen would have more effect on AFC when a considerable number of heifers are inseminated by sexed semen.

Considering the results obtained on this study, it is predicted that utilization of sexed semen would have more effect on AFC of larger herds due to increased popularity of sexed semen among larger herds. In spite of its advantages, the lower conception rate of sex sorted semen beside its larger price is the limiting factor on its popularity. However, the effect of lower conception rate of sex sorted semen on AFC could be ignored if a suitable breeding strategy is applied. A mixed use of sexed and conventional semen is preferred because AFC is less affected by such a strategy. Although limiting the number of SPC leads to a lower AFC, its effect is limited because of larger number of culled heifers. Decisions about the use of sex sorted semen depend on various parameters and economic studies are necessary to evaluate the value of sex sorted semen.

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