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Economic considerations for using sexed semen on Holstein cows and heifers in Estonia

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Abstract. The study investigated economic and managerial considerations for using sexed semen as a tool for accelerated herd expansion and improvement of its genetic potential. Economic value of reproduction strategies based on conventional semen and sexed semen were analysed according to partial budgeting method by Victor E Cabrera and adjusted for the Estonian average indicators. Data for the study were provided by Animal Breeders Association of Estonia. In order to evaluate the economic value of using sexed semen over conventional semen, five different reproductive strategies involving sexed semen were used and compared with conventional semen-based strategy. Average conception rate from the first insemination with conventional semen was 65.6% and 56.1% with sexed semen for Holstein heifers in Estonia in 2015. Probability for birth of a female calf was 49.3% with conventional semen and 93.0% with sexed semen. Net present value for all sexed semen based reproduction strategies was negative at the baseline conditions. Sensitivity analysis for key reproductive and economic variables showed that market price of female calves and conception rates had the most impact on the economic value. Sexed semen can be a valuable tool for reproduction management in dairy farms, but the actual economic value of its application depends on the reproductive performance and objectives of an individual farm. Results of this study provide basis for further research about the situations, where using sexed semen would be economically justified for the farmers.

Key words: sexed semen, reproduction, conception rate, economic value.

INTRODUCTION

Although using sexed semen (SS) has gained popularity among Estonian dairy producers, there have been no studies proving the economic value of SS compared with using conventional semen (CS) on Estonian heifers. The article's methodology is based on Master's thesis by Jaak Härma (Jaak Naaber) (Naaber, 2014) and published in order to spread information from the thesis to improve management skills and support information-based decision making at dairy farms.

The objective of SS is to receive calves of the desired gender (Seidel, 2007; DeVries et al., 2008; Ghavi Hossein-Zadeh et al., 2011). This has created a possibility for dairy producers to accelerate improvement of genetic potential of the herds by getting more female calves from heifers that are genetically superior to the older cows (Seidel, 2007).

The sperms have to be divided into two fractions by the content of either X or Y chromosome to receive offspring of the desired gender (Jaakma et al., 2007). In order to receive a female calf, the cow or heifer has to be inseminated with sperm containing chromosome X (Jaakma et al., 2007; DeVries et al., 2008). Due to time restrictions in the semen separation process, one dose of SS contains about 2 million spermatozoa that is approximately 10 times less than in one dose of conventional frozen bovine sperm (Olynk & Wolf, 2007; Seidel, 2007; DeVries, 2008). Resulting lower fertility of SS is therefore compensated with superior management and using SS predominantly on virgin heifers that have higher fertility than lactating cows (Seidel, 2007).

On average, the ratio of male and female calves born is 50:50 (Hasler, 2014; Jo et al., 2014). Using SS for insemination allows to determine gender of the calf by 85–95% probability (Fetrow et al., 2007; Seidel, 2007; Schenk et al., 2009; Butler & Wolf, 2010; DeVries, 2010; Hutchinson et al., 2013). As female calves become replacements for the herds, their births are important for the economic sustainability of the milk producers.

Economic value of using SS depends upon several criteria. The main benefit comes from higher probability for birth of female calves rather than male calves (Olynk & Wolf, 2007; DeVries, 2008; DeJarnette et al., 2009). Insemination with SS has a high probability of yielding the calf of the desired gender, but conception rate is lower with SS, compared with CS (DeJarnette et al., 2009; DeVries, 2010).

Studies on the return on investment of using SS have concentrated on heifers, as conception probabilities are lower for cows, even when using CS (DeJarnette et al., 2008). Considering that probability of conception decreases further with every unsuccessful insemination, it is economically viable to use SS only with the first insemination and with the following ones only if average conception rates for the whole herd are good (DeVries, 2008).

Several studies in the field of using SS have concluded that using SS in a dairy herd can provide the producers an economic profit compared with using CS, but it is different at each farm and depends on its reproductive and economic performance (Cabrera, 2009; DeVries, 2012; Olynk & Wolf, 2007).

Using SS enables dairy producers to expand their herds more efficiently compared with using conventional semen (Seidel, 2007; Hutchinson et al., 2013). Additional benefit lies in the possibility of internal herd expansion, i.e. without importing animals from outside the farm. It is important from both genetic and bio-security aspect, as introduction of externally sourced animals into herd can result in considerable increase in disease related problems (Faust et al., 2001). SS technology also allows for easier culling of less productive cows (Fetrow et al., 2007).

Objective of the study was to evaluate the potential economic value of insemination of Estonian Holstein heifers with SS as opposed to CS to help dairy producers make economically justified decisions about using SS in their herds. An additional objective was to test the possible advantage of using SS from herd reproduction aspect in the ideal conditions.

MATERIALS AND METHODS

Data for the study were supplied by the Estonian Animal Breeders Association (Eesti Tõuloomakasvatajate Ühistu, ETKÜ), whose 970 clients include the majority of Estonian dairy farms (Bulitko, 2016). ETKÜ supplied the data on reproductive performance of Estonian Holstein heifers and semen prices in 2013–2015. Overall usage of SS in Estonia is still low (Table 1). It should be noted that semen of some popular SS bulls was sold by ETKÜ also as conventional variety; inseminations with these bulls were excluded from the study, as the records did not differentiate reliably between the varieties.

Table 1. Usage data of sexed semen on Holstein heifers in Estonia

	2013	2014	2015
Total inseminations	27,795	35,048	36,299
Inseminations with sexed semen (SS)	1,116	518	1,078
Share of sexed semen in total inseminations	4.0%	1.5%	3.0%
First inseminations with sexed semen (SS)	887	350	776
Share of first inseminations in total SS inseminations	79.5%	67.6%	72.0%

Source: ETKÜ.

Economic value

Methodology of partial budgeting of the survival curves (Cabrera model) (Cabrera, 2009) was applied on the data to evaluate the economic value of using SS over CS. Data received from ETKÜ was used to calculate the net present values (NPV) of various heifer reproduction strategies based on the Cabrera model using Microsoft Excel 2013 application. Using the Cabrera model, it is possible to evaluate the economic value of using SS compared with CS and test the expected additional income and expenses incurred by application of the new technology, assuming that all the other economic conditions remain constant (Cabrera, 2009).

In order to calculate the NPV-s of various heifer reproduction strategies, the basic formulas of the Cabrera model were adjusted to data about Estonian Holstein heifers that was supplied by ETKÜ. Use of NPV is justified because of the interval between consecutive inseminations. After five unsuccessful inseminations the heifer was culled and a pregnant heifer was bought as a replacement (Cabrera, 2009).

Five reproduction strategies using SS were constructed (SS strategy), based on how many inseminations would be done using SS, and compared with a strategy using CS (CS strategy) (Cabrera, 2009).

Sensitivity analysis was performed to evaluate the impact of the most important reproduction and economic parameters on the economic value of using SS versus CS. One or more parameters were changed in the Cabrera model for that purpose.

Reproduction indicators

Data from ETKÜ consist of the average reproduction and economic indicators from association members for Holstein heifers in 2013–2015; data from 2015 has been used as baseline data in this study. Reproduction indicators for heifers are subdivided into key indicators and supplementary indicators. Key reproduction indicators are related to the conception of heifers and probabilities of birth of male or female calves (Table 2). Supplementary indicators are related to data required to calculate the economic value of SS (Table 3). ETKÜ also provided data on individual reproductive performance of 14 farms that were the largest users of SS in 2015.

Table 2. Key reproduction indicators for heifers of member farms of ETKÜ

	2013	2014	2015
Conception rate using CS	66.0%	64.4%	65.9%
Conception rate using SS	44.5%	56.3%	56.1%
Probability of female calf birth using CS	49.3%	48.7%	48.8%
Probability of female calf birth using SS	93.0%	93.0%	93.0%
Probability of male calf birth using CS	50.7%	51.3%	51.2%
Probability of male calf birth using SS	7.0%	7.0%	7.0%

Source: ETKÜ.

Probability for male calf birth was found by subtracting the share of female calves from total number of calves born (100%).

Table 3. Supplementary reproduction indicators for Estonian Holstein heifers

Age of the first insemination (months)	14
No of unsuccessful inseminations before culling a heifer	5
Interval between inseminations (days)	21
Decrease of conception rate with every repeated insemination (%)	5

Source: ETKÜ.

A heifer was first inseminated at the age of 14 months and repeated for 4 additional times if first insemination was not successful. The heifer was culled if it failed to conceive after 5 inseminations. Interval between inseminations was 21 days (if a heifer was observed in oestrus after insemination, then the next insemination would commence after 21 days from the previous one). Probability of conception was reduced by 5% on average with every following insemination.

Economic indicators

There is a range of parameters that have to be considered, when evaluating the economic value of using SS compared with CS. Parameters used in the study are listed in Table 4.

Table 4. Average economic indicators for Estonian Holstein heifers

Cost of one dose of conventional semen (€ per dose)*	6.67
Cost of one dose of sexed semen (€ per dose)*	24.54
Cost of insemination procedure (€ per procedure)**	18.00
Market value of a new-born female calf (€ per head)**	100.00
Market value of a new-born male calf (€ per head)**	75.00
Cost of treatment of dystocia case (€)**	7.00
Rearing cost of an unsuccessfully inseminated heifer (€ per day)**	2.00
Live weight of a non-pregnant, culled heifer (kg)**	550.00
Salvage value of a culled heifer (€ per kg)**	1.20
Market value of a pregnant heifer (€ per head)*	1,300.00
Discount rate (%)***	3.33

Source: *ETKÜ statistics; **ETKÜ estimates; *** (Bank of Estonia 2016).

Average price of one dose of CS and SS sold by ETKÜ was €6.67 and €24.54 respectively in 2015. Cost of one insemination procedure was estimated at €18.00. Total cost of semen dose and insemination procedure corresponds to cost of semen dose as defined in Cabrera model (€24.67 for CS and €42.54 for SS, respectively).

Results of all inseminations and reproduction strategies were computed in present values, in order to obtain economically fair results (Naaber, 2014). Average short-term interest rate (3.33%) charged by credit institutions from non-financial borrowers in agriculture, forestry and fishing in Estonia in 2015 was used as the discount rate for present values (Bank of Estonia, 2016). The same average interest rate for 2013 was 3.24% (Bank of Estonia, 2016), the difference would have no significant impact on the results of the study.

Impact on reproductive performance

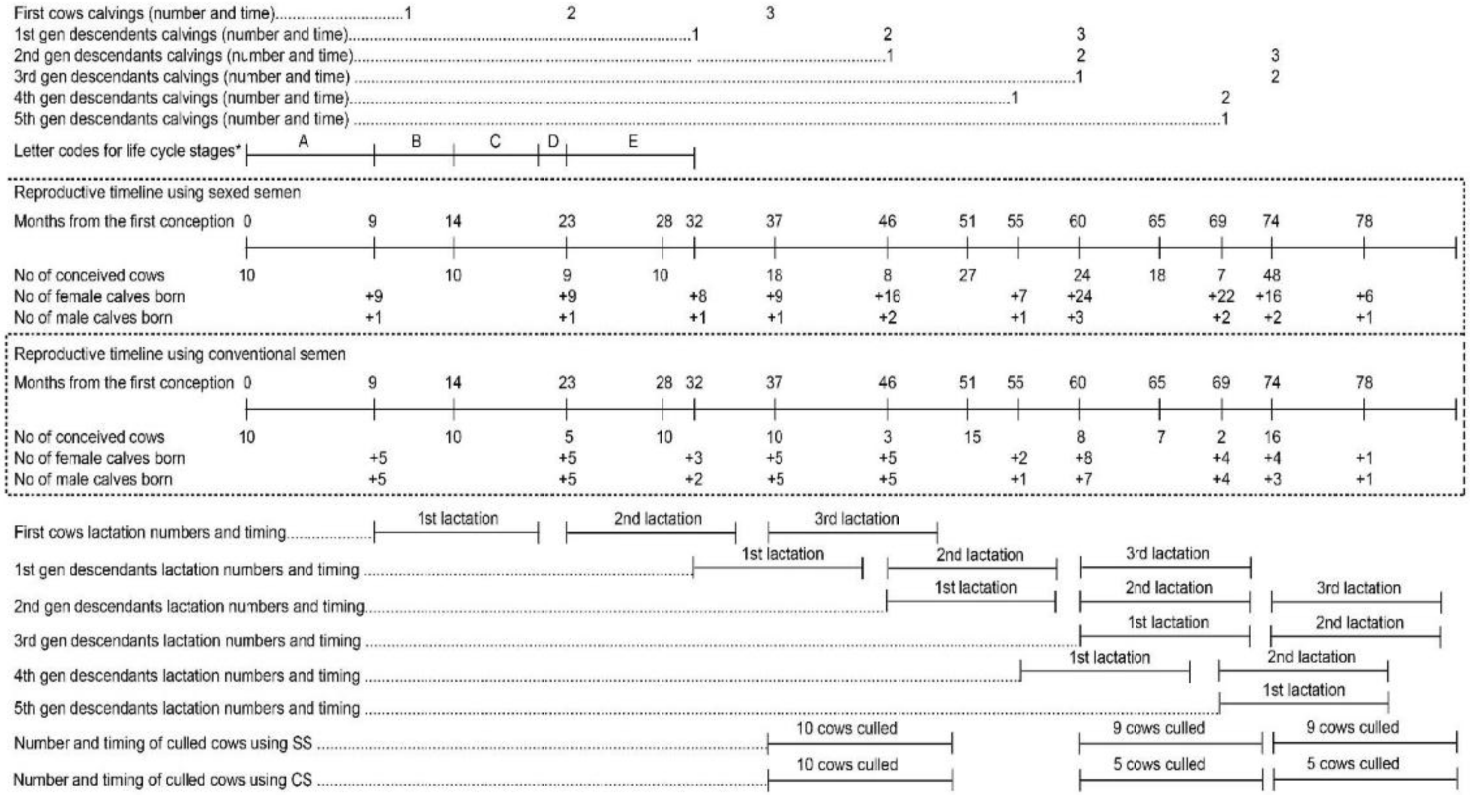
Illustrative timeline (Fig. 1) was created to describe the impact on using SS on the reproductive performance of a herd. It was based on 10 heifers that were inseminated with SS and CS in ideal conditions. Duration of the timeline was 6.5 years and the ideal conditions were the following:

1. Conception rate with both SS and CS was 100%;
2. Probability of female calf birth with SS was 90%;
3. Probability of male calf birth with SS was 10%;
4. Probability of female calf birth with CS was 50%;
5. Probability of male calf birth with CS was 50%;
6. Stillbirths, abortions, diseases and other causes of premature death were excluded;
7. Cows were culled after three lactations;
8. All born female calves were used as replacements to the herd.

The following parameters were used to construct the timeline:

1. Gestation length: 9 months or 275–282 days;
2. Calving interval: 418 days;
3. Length of lactation: 305 days;
4. Length of dry period: 67 days;
5. Average age of the first conception of a heifer: 14 months;
6. Average age of the first calving: 23 months
7. Cows were culled after three lactations.

Although lactation period and dry period preceding calving have lasted for 374 days or slightly over 12 months in total, they were linked with calving interval (14 months) on the timeline. Age of the first conception was linked to the age of the first insemination. As ideal conditions presumed conception rate of 100% using both CS and SS, then the age of the first calving was linked to age of the first insemination (14 months) and length of gestation (9 months). As a result, the cows on the timeline were 23 months old at the first calving. Average age of Estonian Holstein cows was 4 years and 6 months in 2013 (Jõudluskontrolli Keskus, 2014), therefore the cows were culled after three lactations in the model (Naaber, 2014).



*Letter codes for life cycle stages: A: gestation, A+B: calving interval, B+C: lactation, D: pre-calving dry period, B+C+D: age of heifer at the first conception, B+C+D+E: age of heifer at the first calving.

Conditions: ideal reproduction conditions for dairy herds. Conception rate: 100% for both SS and CS. Probability of female calf birth using SS: ~90%, probability of male calf birth: ~10%, probabilities for birth of female and male calves using CS: ~50%. No stillbirths, abortions, traumas, diseases or other causes for premature death considered. Cows are culled after 3 lactations. All female calves used to complement the herd.

Figure 1. Reproduction timeline using SS and CS in ideal conditions. Source: Naaber, 2014. Updated with Estonian animal recording data from 2015, where applicable (Eesti Põllumajandusloomade Jõudluskontrolli AS 2016).

RESULTS

Economic impact

Results on the economic impact of using SS are presented in Table 5. For ETKÜ members, NPV of the first insemination of heifers with SS was -€24.43. Using SS for two of the first inseminations of heifers, NPV was -€47.30. Using SS for three of the first inseminations of heifers, NPV was -€69.35. If SS were used for all five inseminations of heifers, NPV would be -€112.44. This shows that at the given conditions, using SS is not economically profitable compared with using CS and every repeated insemination with SS increases the economic loss for the dairy producer compared with using CS.

Table 5. Economic impact of the reproductive strategies using sexed semen (2015 results)

First insemination with sexed semen	-24.43 €
2 first inseminations with sexed semen	-47.30 €
3 first inseminations with sexed semen	-69.35 €
4 first inseminations with sexed semen	-91.00 €
All 5 inseminations with sexed semen	-112.44 €

Source: ETKÜ.

Results of sensitivity analysis of the economic impact of using SS are presented in Table 6. Current analysis shows that if conception rate of the heifers using CS were 80%, NPV of the first insemination using SS strategy would decrease by €8.28. If SS were used for all five inseminations, NPV of this strategy would decrease by €27.40.

Decreasing conception rate of the heifers using SS by 10 percentage points, the respective economic loss from using SS versus CS would be €38.76 if using SS only for the first insemination. Compared with the baseline assumptions, the economic loss would increase by €14.34.

Raising market value of female calves by €200 per head, using SS for the first insemination would produce an economic profit of €23.60 over using CS. The results indicate that economic value of using SS depends the strongest on conception rate and market value of female calves.

Decreasing conception rate of the heifers inseminated with SS by 10 percentage points and increasing market value of a female calf by €200, the economic value of using SS or CS for the first insemination would be practically equal.

Overall low conception rates (50% for CS and 35% for SS) result in deeper economic loss from using SS that is not compensated for by higher female calf value.

If price of one dose of SS would decrease to €30 and market value of a female cow would rise by €100, then the economic profit of using SS for the first insemination were €11.88 With market value of a female calf at €300 and conception rates equal to the average of CS at 65.9%, using SS would produce an economic profit compared with CS in all strategies.

Table 6. Impact of reproductive and economic parameters on the economic value of using sexed semen technology at ETKÜ member farms

Conception rate using conventional semen (%)	Conception rate using sexed semen (%)	Cost of one dose of sexed semen (€)	Market price of a new-born female calf (€)	Economic value of using sexed semen (€)				
				Reproductive strategies involving use of sexed semen				
Baseline economic and reproductive parameters (Table 2,Table 4)				1	2	3	4	5
65.9	56.1	42.54	100	-24.43	-47.30	-69.35	-91.00	-112.44
Impact of one parameter on the reproductive strategies								
80	56.1	42.54	100	-32.71	-59.66	-85.12	-111.34	-139.84
65.9	46.1	42.54	100	-38.76	-73.42	-107.14	-141.76	-178.50
65.9	65.9	42.54	100	-10.38	-25.48	-41.85	-58.51	-75.17
65.9	56.1	30	100	-12.14	-22.84	-32.86	-42.59	-52.25
65.9	56.1	42.54	300	23.60	19.44	5.24	-12.99	-33.00
Combined impact of parameters on reproductive strategies								
65.9	46.1	42.54	300	0.02	-16.96	-42.58	-73.93	-110.18
65.9	56.1	30	200	11.88	10.52	4.43	-3.59	-12.53
50	35	42.54	100	-49.06	-95.36	-140.74	-186.31	-232.74
50	35	42.54	300	-21.11	-53.32	-92.01	-135.18	-181.97
65.9	65.9	42.54	300	46.71	49.41	39.37	25.23	9.67

Reproductive impact

Impact of using SS on herd reproduction was estimated by a comparative timeline of herd dynamics in ideal conditions using SS and CS. The first calves from heifers inseminated with both SS and CS in the ideal conditions were born during the 9th month of gestation. As there were initially 10 inseminated heifers in both groups, then there were 9 female calves and 1 male calf born from the SS group and 5 female calves and 5 male calves born in the CS group. The first cows calved on the 9th, 23rd and 37th months after the first conception and were culled from the herd after the third lactation. In total, the first cows from the SS group gave birth to 27 female calves and CS group to 15 female calves (Naaber, 2014).

As all female calves born were used to complement the herd, then the first generation of the offspring were inseminated on the 23rd month. First calves from the first generation offspring were born on 32nd month. The first generation of offspring gave birth to 8 female calves from SS group and 3 female calves from the CS group. The first offspring calved on 32nd, 46th and 60th month. In total for all three calvings, the first offspring from the SS group gave birth to 15 more female calves than CS group. Altogether, the first cows and their five generations of descendants gave birth to 126 female calves in the ideal conditions if inseminated with SS and 42 female calves if inseminated with CS during the observation period of 6.5 years. (Fig. 1)

According to the findings of the current study using SS can substantially increase supply of internally produced heifers compared with CS, enabling herd expansion, increase of genetic potential of the herd, or opening a new income stream from heifer sales, depending on the strategy of the farm. The economic analysis, in turn, suggested that, at the baseline conditions, choice of using SS does not create positive economic value for the dairy producers compared with using CS. Results of this study help dairy farmers evaluate the advantages and drawbacks of SS technology, considering their strategic objectives and the conditions at the farms.

DISCUSSION

Reproductive performance at the farm level

As conception rates are the highest from the first insemination (Kuhn et al., 2006), then performing only the first one with SS allows to realise a significant part of the potential reproductive benefit of SS, while limiting the economic loss per animal. According to the current study, the economic loss from using SS for the first insemination was €24.43, using SS for 5 (all) inseminations the economic loss would grow to €112.44 at the baseline conditions. The outcome is in line with other studies that have found that using SS for all inseminations would produce an economic profit only at practically unrealistic conception rates or very high prices of female calves (Olynk & Wolf, 2007; DeVries, 2012). Considering that, it was surprising that 20–30% of all inseminations with SS were repeated inseminations (Table 1). Moreover, on the aggregate level the number of repeated inseminations increased from 20.5% in 2013 to 28% of all SS inseminations in 2015, but at the same time, conception rate also increased significantly, from 44.5% to 56.1% (Table 2).

We hypothesised that these trends could be due to changes in the list of farms that used SS over the three-year period – farms achieving satisfactory results expanding SS use into repeated inseminations as well and those with poor results reducing or stopping use even on the first inseminations. Unfortunately, detailed data on individual reproductive performance in all farms using SS was not available, but ETKÜ could supply data on the 14 largest individual users of SS that in total used 52% of all SS doses sold by ETKÜ in Estonia in 2015. As some of these farms used SS mostly or exclusively on cows, data from 11 farms was analysed as part of this study to gain an insight into effectiveness of SS use on heifers at the farm level. Together, these farms performed 37.4% of all Holstein heifer inseminations using SS by the clients of ETKÜ in 2013 to 2015 (Table 2). Three years' data were analysed in aggregate form as annual datasets were relatively small.

Data suggests that intensity of SS use and conception rates do vary to a large degree and farms with the lowest results may be considering discontinuation of using SS technology, as based on the economic value analysis it is likely negative for them (Table 7). Based on this data, farms with below-average conception rates with CS tend to have uneconomically low conception rates with SS – confirming the view that application of SS in herds with conception problems is likely to deepen, not solve these problems. On the other hand, the data also suggests that it is possible to achieve high conception rates (over 55%) with SS. Managerial practices regarding application of SS technology at the successful farms warrant further research.

Table 7. Reproductive performance at selected farms using sexed semen on Holstein heifers in 2013–2015 (aggregate)

Farm no	No of SS inseminations	No of CS inseminations	Share of SS (%)	Conception rate (CR) using SS (%)	Conception rate (CR) using CS (%)	Difference in CR (%)
1	70	486	12.6	62.9	48.8	-14.1
2	236	2517	8.6	58.7	72.0	13.3
3	142	835	14.5	62.9	67.0	4.1
4	64	565	10.2	54.2	77.9	23.8
5	61	1,769	3.3	26.7	55.9	29.2
6	97	988	8.9	46.4	72.0	25.6
7	45	556	7.5	81.6	72.8	-8.8
8	65	99	39.6	53.2	54.2	1.0
9	107	363	22.8	44.4	58.4	14.0
10	84	891	8.6	35.1	53.9	18.8
11	44	351	11.1	58.1	74.0	16.0
Total	1,015	9,420	9.7	54.0	66.6	12.6

Source: ETKÜ.

Value of female calves

Sensitivity analysis demonstrated that value of a female calf has the strongest impact on the economic value of using SS. The result is in line with that of a broad-based feasibility study of factors affecting feasibility of SS (McCullock et al., 2013). A study of two large herds in the US recommended using SS for the first insemination to the herds that plan expansion. In their case, however, value of a new-born female calf was estimated at $250 and male calf at $50, meaning a fivefold difference in values (Chebel et al., 2010). De Vries (2008) refers to an even larger difference in values of male and female calves ($50 vs $450 per head)[1] (DeVries, 2008). In ETKÜ estimations, value of a female calf is only a third higher than that of a male calf (€100 and €75, respectively). There are also notable differences in the proportion of new-born female calf value to pregnant heifer value between suggestions of ETKÜ and data used in the US studies. De Vries (2008) estimates that sales price of a female calf is approximately 25% of the value of a pregnant heifer. Chebel et al. (2010) estimate that a female calf is worth 17.8% of the value of a pregnant heifer. ETKÜ data estimates that a female calf is only worth 7.7% of the value of a pregnant heifer. This gap implies that €100 per head value assigned to new-born female calves and thus the economic value of using SS may be underestimated. For a farm, intrinsic value of a new-born female calf is essentially the difference between market price of a pregnant heifer and cost of raising the calf into a pregnant heifer itself (DeVries, 2008). A comprehensive study of heifer rearing costs in Estonia is needed to confirm this hypothesis.

Impact of SS on stillbirths

Another aspect that needs further research is the impact of using SS on the incidence of stillbirths on the heifers. Results from the studies to date have been inconclusive. DeJarnette et al. (2009) found that SS technology increased incidence of

[1] Official exchange rate was 1.3917 USD/EUR as of 31/12/2008 and 1.0887 USD/EUR as of 31/12/2015 (European Central Bank, 2016).

stillbirths among the (unwanted) male calves, but it did not significantly affect the total incidence of stillbirths. Chebel et al. (2010) reported a significantly higher stillbirth incidence among female calves conceived using SS technology (10.7% vs 4.7% in one herd and 7.1% vs 3.8% in the other herd). Norman et al. found that incidence of stillbirths among single female calves was somewhat higher using SS than CS (9.7% vs 10.8%) based on 1.3 million inseminations in the US (Norman et al., 2010). No comparable data exists for Estonian herds today.

Herd expansion

Using SS also needs to be researched from herd expansion aspect. Average Estonian Holstein cow has the first calving at the age of 26.4 months and is culled from the herd at the age of 63 months (average for all dairy breeds) according to animal recording data (Eesti Põllumajandusloomade Jõudluskontrolli AS, 2016). With calving interval of 14 months, an average Holstein cow stays in the herd for 2.5 lactations. Accordingly, calves born to heifers represent approximately 40% of all calves born. If an average herd has also high calves and heifers culling rate, it is difficult to maintain the herd size without purchasing heifers from outside. SS could provide an alternative to heifer purchasing for such herds, while eliminating the bio-security risks related to outside animals.

CONCLUSION

Results from this study confirm that using SS enables dairy producers to increase supply of heifers to accelerate increase of the genetic potential and/or size of the herd from within the herd. However, the economic value of using this technology depends on the market prices of calves and reproductive performance of an individual herd. At the average reproductive performance at ETKÜ member farms in 2015 and respective market conditions, using SS is not economically justified.

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