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The value of sexed bovine semen

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Summary

Semen sexing may be used in a variety of practical situations, where part (or all) of the herd may be inseminated with X- and Y-chromosome-enriched semen. Expressions are presented to calculate the net present value of progeny derived from a semen dose, dependent on the values of females and males, and on the efficiency of sexing. Sexed semen allows selling a higher proportion of the more valuable sex and also increases the value of animals retained for breeding through more intense selection. The expressions to economically evaluate sexed semen are quite general but numerical examples are presented for several practical situations of interest in Brazil.

Zusammenfassung

Der Wert von gesextem Rindersperma

Das Sexen von Spermien kann in einer Vielzahl von praktischen Situationen genutzt werden, wenn jeweils ein Teil oder die ganze Herde mit X- und/oder mit Y-Chromosom-angereichertem Sperma besamt werden sollen. Zur Kalkulierung des Netto-Werts dieser Nachkommen werden von der Samendosis abgeleitete Berechnungen in Abhängigkeit von den Werten der weiblichen und männlichen Tiere und der Effektivität des Sexens präsentiert. Gesexte Spermien erlauben den Verkauf eines höheren Anteils des wertvolleren Geschlechts und steigern auch durch die intensivere Selektion den Wert der für die Zucht genutzten Tiere. Die Berechnungen zur ökonomischen Bewertung für gesexte Spermien sind recht allgemein, aber es werden numerische Beispiele für einige praktische Situationen in Brasilien präsentiert.

Introduction

Techniques for sorting bovine semen into X- and Y-chromosome-bearing spermatozoa are becoming reasonably efficient and may soon be commercially available in Brazil as elsewhere, providing an important tool to economically improve cattle production (JOHNSON 2000; CUMMING 2002; GUUS LAEEVEN, personal communication). HOHENBOKEN (1999) and SEIDEL (2003) reviewed studies on the economics of sexed semen and presented calculations for various practical situations. The objective of this paper is to present a general expression to quantify the profit derived from the use of sexed semen.

Rationale

It is considered that X- and Y-chromosome bearing spermatozoa are available. The analysis is based on the net present value expected from a semen dose (EVERETT 1975; MADALENA 1986) that may produce four progeny categories: males and females, both for sale or retained for breeding. The proportions and values of these categories influence the value of sexed semen. Increasing the proportion of females would be desirable in dairy cattle production and increasing the proportion of males would be desirable in beef cattle production. Define: subscripts i , indicating sex (f, m) and j , for category (b, retained for breeding; s, for sale);

c is the probability of a semen dose resulting in a calf born;
 x_f is the probability of a female calf by X-enriched semen;
 y_m is the probability of a male calf by Y-enriched semen;
 s_{ij} is the survival rate from birth to age at sale or to birth of first progeny;
 cr is the herd calving rate;
 r is the herd replacement rate;
 p_i is the selected proportion of breeding animals of the i th sex;
 P_X is the proportion of the herd inseminated to X-chromosome enriched semen.
 v_{ij} is the net present value of a female/male progeny for breeding/sale;
 C_X and C_Y is the cost of a dose of X- and Y-enriched semen, respectively.

The net present value of a progeny is the difference between the sale price and rearing expenses, discounted at interest rate i by a factor $d = (1 + i)^{-t}$ to time of insemination ($t = 0$). The expected net present value of a female/male progeny is the weighted average of the value of sale and breeding females/males multiplied by their probability of survival, i.e.

$$v_i^* = p_i s_{ib} v_{ib} + (1 - p_i) s_{is} v_{is} \quad (1)$$

In a general situation, consider that X-enriched semen is used on a P_X portion of the herd and Y-enriched semen on the remaining $1 - P_X$. Some females are generated by Y-enriched semen ($1 - y_m$) and some males by X-enriched semen ($1 - x_f$). The expected net present value of a progeny by a semen dose is then

$$VC_{XY} = c\{P_X[x_f v_f^* + (1 - x_f)v_m^*] + (1 - P_X)[(1 - y_m)v_f^* + y_m v_m^*]\} \quad (2)$$

The expected net present value of a semen dose is the net present value of a calf minus the dose price,

$$VS_{XY} = VC_{XY} - [P_X C_X + (1 - P_X)C_Y] \quad (3)$$

All females desired

In this case all inseminations are by X-enriched semen ($P_X = 1$) and no breeding males are retained ($p_{mb} = 0$), so $v_f^* = p_{fb} v_{fb} + (1 - p_f) s_{fs} v_{fs}$ and $v_m^* = s_{ms} v_{ms}$. To keep herd size constant r female replacements per breeding female must enter the herd annually and $p_f = r/(x_f cr s_{fb})$.

The expected net present value of a calf obtained from a semen dose is

$$VC = c[x_f v_f^* + (1 - x_f)v_m^*] = cv_m^*[1 + (k - 1)x_f] \quad (4)$$

where $k = v_f^*/v_m^*$.

With perfect sexing ($x_f = 1$), $VC = cv_f^*$ while for non-sexed semen ($x_f = 1/2$), $VC_{1/2} = c(v_f^* + v_m^*)/2$. The ratio of female to male calf values, $k = v_f^*/v_m^*$ is key to the value of sexed semen. When both sexes have equal value ($k = 1$) there is no benefit in sexing, otherwise the value expected from a semen dose increases or decreases with x_f , by $cv_m^*(k - 1)$.

Value of breeding animals

Sexed semen allows for higher selection intensity of breeding females or males, which should increase profit from descendants in successive generations. The genetic superiority of replacements selected by truncation on a profit index (I_i) is $\Delta G_{ib} = i_{ib} \sigma_{I_i}$, and will be expressed N times in the descendants, accumulated over a given time horizon. McCLINTOCK and CUNNINGHAM (1974) defined a standard unit of expression as *one*

expression of the trait in the progeny in the year in which insemination took place. They introduced the discounted gene flow method to calculate N , accounting for the halving of genetic superiority in each generation and for the financial cost of the investment in semen. In the present case, the added net present value of retained female replacements because of selection is $N i_{fb} \sigma_{If}$, so

$$v_{fb} = v_{fs1} + N i_{fb} \sigma_{If} \quad (5)$$

where v_{fs1} indicates value of females at first calving. In dairy cattle adult traits are of interest and likely retained and sold females would be by the same sires, so selection of heifers would be based on their dams index, so the extra superiority is rather

$$v_{fb} = v_{fs1} + \frac{1}{2} N i_{fb} \sigma_{If}. \quad (5a)$$

However, in an idealized situation where all marketed females were selected with equal intensity on the same profit index, the genetic value of sold heifers would be $i_{fs} \sigma_{If}$, so $\Delta G_{fb} - \Delta G_{fs} = (i_{fb} - i_{fs}) \sigma_{If} = i_{fb} \sigma_{If} / (1 - p_f)$ and $v_{fb} = v_{fs1} + 1/2 [i_{fb} / (1 - p_f)] N i_{fb} \sigma_{If}$.

The selection intensity of females may be conveniently approximated by the expression of SMITH (1969), modified by HILL (1971), $i_{fb} \approx 0.8 + 0.41 \ln [(1/p_f) - 1]$. VAN VLECK and EVERETT (1976) used an equivalent approach to calculate the economic return of sexed semen based on transition matrices.

Maximum number of males desired

In this case Y-enriched semen would be used, but a minimum proportion of females would still be needed for replacement. Y-enriched semen generates y_m males and $1 - y_m$ females, so when $y_m \leq 1 - r/(cr s_{fb})$ there will be enough replacements, but otherwise, with high efficiency of male sorting, a proportion P_X of breeding females would need to be inseminated to X-enriched semen, i.e. $P_X = [(r/cr s_{fb}) - (1 - y_m)] / (x_f + y_m - 1)$ if $(1 - y_m)cr s_{fb} < r$ and $P_X = 0$ otherwise.

The value of females may still be calculated by (1), considering that $p_f = r/[(1 - y_m)cr s_{fb}]$ if excess females are produced [i.e. if $(1 - y_m)cr s_{fb} > r$] and $p_f = 1$ otherwise, so $i_{fb} = 0$.

Examples

Some examples are presented for Brazilian circumstances. Realistic assumptions were used, but this is not very important as expressions (1) to (5) may be evaluated by plugging in any appropriate values as desired.

In all cases a time horizon of 15 years and discount factor of $0.94^{t/12}$ were considered (t in months). It was assumed that a user of sexed semen would continue to do so over the 15-year horizon. All monetary values are expressed in US dollars.

Two sets of calculations were made: (i) considering equal conception rates ($c = 0.67$) for both sexed and non-sexed semen, and (ii) considering lower conception rate for sexed ($c = 0.60$) than for non-sexed semen ($c = 0.67$). The latter is currently a more realistic assumption (SEIDEL 2003).

Dairy production

In this example a commercial dairy farm based on Holstein cattle is considered. Males are sold for slaughter at five days of age and excess females are sold at 3, 12 or 24 months. Two situations are considered:

- i. Straight breeding.
- ii. Straight breeding for replacements and crossbreeding to Gir to produce surplus females (currently a popular alternative in Brazil and Colombia, as high prices are paid for the F_1 heifer calves).

In both cases the females retained for breeding were selected as intensively as possible. However, as genetic evaluation is not likely to be in place, results are shown for selection and non-selection circumstances.

To calculate N , up to 12 lactations per cow were considered, with stayabilities and optimal replacement rate ($r = 0.218$) as in CARDOSO et al. (1999) and lactation curve as in GONÇALVES et al. (2002). Age at first calving of 27 months, calving interval of 13 months, $\sigma_{ft} = \text{US\$ } 10/\text{lactation}$ and $cr = 0.92$ were assumed.

Beef production

Two situations were considered (both with $cr = 0.83$ and $r = 0.11$):

- i. A beef ranch selling either weaner calves or fat steers. Female numbers were set at the minimum required for replacement and the excess, if any, sold at weaning.
- ii. A multiplier beef breeder, selling 2-year-old bulls and excess females at weaning, not retaining males for breeding ($p_m = 0$).

Evaluations of (2) are in Tables 1 and 2. Results are presented in terms of the monetary superiority of sexed over non-sexed semen, $VC_{XY} - VC_{1/2}$. In the dairy farm example, the

Table 1. Increase in expected net present value of a progeny by a dose of sexed over non-sexed semen in various circumstances, considering equal conception rate for both semen types ($c = 0.67$)¹

Assumptions						Efficiency of X/Y chromosome sorting				
Females sold			Males sold			0.6	0.7	0.8	0.9	1.0
Age (months)	v_{fs}^2 US\$	s_{fs}^3	Age (months)	v_{ms}^2 US\$	s_{ms}^3	Increase in value over non-sexed semen US\$				
Dairy farm. Straightbred females sold. Selection on dam profit index										
3	6	0.92	0	5	0.90	0.29	0.44	0.54	0.63	0.71
12	13	0.90	0	5	0.90	0.75	1.36	1.92	2.47	3.01
24	59	0.85	0	5	0.90	3.28	6.41	9.50	12.57	15.63
Dairy farm. Straightbred females sold. No selection on dam index										
3	6	0.92	0	5	0.90	0.06	0.12	0.18	0.24	0.30
12	13	0.90	0	5	0.90	0.52	1.04	1.56	2.07	2.59
24	59	0.85	0	5	0.90	3.04	6.09	9.13	12.18	15.22
Dairy farm. F_1X dairy Zebu females sold. No selection on dam index										
3	20	0.95	0	5	0.90	0.96	1.92	2.88	3.84	4.79
12	71	0.94	0	5	0.90	4.19	8.38	12.57	16.76	20.95
24	330	0.90	0	5	0.90	19.52	39.03	58.55	78.06	97.58
Beef ranch. Males and excess (minimum) females sold										
8	9	0.96	8	11	0.96	0.12	0.24	0.36	0.43	0.43
8	9	0.96	30	41	0.94	1.97	3.94	5.91	7.08	7.08
Multiplier beef breeder. Bulls and excess (minimum) females sold										
8	15	0.96	24	755	0.94	46.37	92.74	139.11	166.71	166.71

¹Evaluations of (2) based on the assumptions shown in the first six columns. Cost of semen not included in the calculations.
²Net present value.
³Survival rate to age sold.

Table 2. Increase in expected net present value of a progeny by a dose of sexed over non-sexed semen in various circumstances, considering lower conception rate for sexed ($c = 0.60$) than for non-sexed semen ($c = 0.67$)¹

Assumptions						Efficiency of X/Y chromosome sorting				
Females sold			Males sold			0.6	0.7	0.8	0.9	1.0
Age (months)	v_{fs}^2 US\$	s_{fs}^3	Age (months)	v_{ms}^2 US\$	s_{ms}^3	Increase in value over non-sexed semen US\$				
Dairy farm. Straightbred females sold. Selection on dam profit index										
3	6	0.92	0	5	0.90	-1.33	-1.20	-1.11	-1.03	-0.96
12	13	0.90	0	5	0.90	-1.02	-1.48	0.03	0.52	1.01
24	59	0.85	0	5	0.90	0.69	3.51	6.29	9.05	11.81
Dairy farm. Straightbred females sold. No selection on dam index										
3	6	0.92	0	5	0.90	-1.13	-1.07	-1.02	-0.97	-0.91
12	13	0.90	0	5	0.90	-0.82	-0.35	0.12	0.58	1.05
24	59	0.85	0	5	0.90	0.90	3.64	6.38	9.12	11.86
Dairy farm. F_1X dairy Zebu females sold. No selection on dam index										
3	20	0.95	0	5	0.90	-0.52	0.35	1.21	2.07	2.94
12	71	0.94	0	5	0.90	1.68	5.45	9.22	12.99	16.76
24	330	0.90	0	5	0.90	12.08	29.64	47.21	64.77	82.33
Beef ranch. Males and excess (minimum) females sold										
8	9	0.96	8	11	0.96	-1.86	-1.75	-1.64	-1.58	-1.58
8	9	0.96	30	41	0.94	-1.12	0.65	2.42	3.47	3.47
Multiplier beef breeder. Bulls and excess (minimum) females sold										
8	15	0.96	24	755	0.94	16.32	58.05	99.78	124.62	124.62

¹Evaluations of (2) based on the assumptions shown in the first six columns. Cost of semen not included in the calculations.
²Net present value.
³Survival rate to age sold.

value of sexed semen increases continuously with the efficiency of sexing (x_i). In the beef cattle examples, however, the value increases up to a certain efficiency of sexing and it then remains constant thereafter, because the proportion of females is set at the minimum for all values of $y_m > 1 - (r/cr s_{fb})$ ($=0.859$ in this examples), by regulating P_x , the proportion of the herd inseminated with X-enriched semen.

Discussion

The expected net present value of a progeny given by expression (2) is equivalent to the break-even premium for sexed sperm (SEIDEL 2003). As noted by HOHENBOKEN (1999), ‘profitability of sexed semen will depend not only upon its cost but also upon the prevailing economic conditions in the industry and for individual farms.’ Average semen prices paid by commercial dairy and beef farmers in Brazil are in the order of US\$ 4 and 6 per dose, respectively, which may be taken into consideration to interpret the results in Tables 1 and 2. No sexed semen is as yet being marketed in Brazil, so the results may not be compared with actual prices.

The examples in Tables 1 and 2 illustrate that the advantage of sexed over non-sexed semen is higher for high-value animals, such as breeding bulls, and for larger differences in the value of the animals sold of each sex. Thus, in commercial weaner beef calf production the advantage in sexing is not as large as in fat steer production, where the difference in values of males and females is much larger. SMEATON and VIVANCO (2002) also noted that the value of semen sexing in embryo transfer for beef production was dependant on the

differences in value between male and female calves. RUVUNA *et al.* (1992) found important benefits from increased male proportions to produce cloned beef cattle sires.

The contribution of increased selection intensity on dam index to the value of sexed semen was rather small, as illustrated in the dairy example. The increased value of the replacement heifers caused by the more intense selection practiced with sexed semen was partly offset by a lower number of discounted expressions, because of the lower chance of a heifer entering the herd when more of them were available. For example, for $c = 0.67$, the proportion of heifers retained was 0.55 with non-sexed semen ($x_f = 1/2$) and half of that with perfect sexing ($x_f = 1$), which increased the genetic merit in the latter case by US\$ 4.8. However, the number of discounted lactations of a heifer progeny entering the herd was reduced from 7.5 to 4.9, so the genetic merit added a similar proportion to the value of the replacement heifer in both cases, 0.30 and 0.32, respectively.

The specialized dairy farm would profit more from sexing than the commonest Brazilian dairy farm raising both males and females, as the difference in value between sexes is larger when bobby calves are slaughtered. For the same reason, sexing is more advantageous for the specialized dairy farm producing high valued F_1 dairy Zebu crosses as excess females. Thus, HOHENBOKEN'S (1999) conclusion, that use of sexed semen would make terminal crossbreeding systems more efficient and sustainable in beef cattle, also applies in this case.

Selling older animals gives higher advantage from sexing. However, raising more surplus animals would change the allocation of farm resources to the different categories, which may or may not be economical. For example, a dairy farm using sexed semen would need land and resources to raise the increased number of heifers. To assess whether those resources would be better allocated to heifers or to milking cows would require a system analysis beyond the scope of this article.

Although the main purpose of this article is not to explore the variety of possibilities of using sexed semen, already covered by HOHENBOKEN (1999) and SEIDEL (2003), it is interesting to note, as suggested by the referees, the overriding effect of the conception rate on the potential benefits from semen sexing. As it is well known, artificial insemination will not be economic when fertility is low, and this is reflected in expression (2), where the expected net present value of a progeny by a semen dose is proportional to the conception rate. Expression (2) may also be used to calculate the economic effect of a reduction in fertility of sexed semen, by just plugging in the appropriate conception rates. For example, by comparing the results of Tables 1 and 2, it may be seen that 10% reduction in the fertility of sexed semen markedly decreased its profitability, which even became negative in several cases.

It was pointed out to us that in many situations it would be an option to use sexed semen only for certain animals (e.g. for designated bull dams), and non-sexed semen for others. Expression (2) may also be applied to non-sexed semen, considered a particular case where X- and Y-chromosome bearing spermatozoa are equally likely, by setting either x_f or y_m to 1/2 (or some other suitable probability). Other situations, such as the effects of dystocia or the calf's genotype on milk yield, may also be accommodated (increasing the cost) into the calculation of the net present value of the progeny.

The analysis presented did not consider the long-term consequences. Should semen sexing become widely adopted, the increased production of females might likely result in a price reduction. This may not be very important in an expanding livestock industry such as the Brazilian, but it may apply to other countries. Based on a similar analysis, OCHOA *et al.* (1991) concluded that the use of sexed semen may only be appropriate in dairying when it can generate additional income from the sale of surplus heifers.

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