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Genetic gain and economic values of selection strategies including semen traits in three- and four-way crossbreeding systems for swine production[1]

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ABSTRACT: Four semen traits: volume (VOL), concentration (CON), progressive motility of spermatozoa (MOT), and abnormal spermatozoa (ABN) provide complementary information on boar fertility. Assessment of the impact of selection for semen traits is hindered by limited information on economic parameters. Objectives of this study were to estimate economic values for semen traits and to evaluate the genetic gain when these traits are incorporated into traditional selection strategies in a 3-tier system of swine production. Three-way (maternal nucleus lines A and B and paternal nucleus line C) and 4-way (additional paternal nucleus line D) crossbreeding schemes were compared. A novel population structure that accommodated selection for semen traits was developed. Three selection strategies were simulated. Selection Strategy I (baseline) encompassed selection for maternal traits: number of pigs born alive (NBA), litter birth weight (LBW), adjusted 21-d litter weight (A21), and number of pigs at 21 d (N21); and paternal traits: number of days to 113.5 kg (D113), backfat (BF), ADG, feed efficiency (FE), and carcass lean % (LEAN). Selection Strategy II included Strategy I and the number of usable semen doses per collection (DOSES), a function of the 4 semen traits. Selection Strategy III included Strategy I and the 4 semen traits individually. The estimated economic values of VOL, CON, MOT, ABN, and DOSES for 7 to 1 collections/wk ranged from \$0.21 to \$1.44/mL, \$0.12 to \$0.83/10^3 spermatozoa/mm^3, \$0.61 to \$12.66/%, −\$0.53 to −\$10.88/%, and \$2.01 to \$41.43/%, respectively. The decrease in the relative economic values of semen traits and DOSES with higher number of collections per wk was sharper between 1 and 2.33 collections/wk than between 2.33 and 7 collections/wk. The higher economic value of MOT and ABN relative to VOL and CON could be linked to the genetic variances and covariances of these traits. Average genetic gains for the maternal traits were comparable across strategies. Genetic gains for paternal traits, excluding semen traits, were greater in selection Strategy I than Strategies III and II. Genetic gains for paternal and maternal traits were greater in the 4- and 3-way schemes, respectively. The selection strategy including the 4 semen traits is recommended because this approach enables genetic gains for these traits without compromising the genetic gains for maternal traits and with minimal losses in genetic gains for paternal traits.

Key words: crossbreeding systems, economic value, semen traits

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INTRODUCTION

In crossbreeding systems for swine production, selection decisions tend to prioritize reproductive traits in maternal lines and growth and carcass traits in paternal lines. Although boar fertility plays an important role in the efficiency and productivity of the system, semen traits are usually absent from selection decisions (Rothschild, 1996; Smital et al., 2005; Ruiz-Sanchez et al., 2006).

Most common semen traits include measurements of ejaculate volume (**VOL**, mL), sperm concentration (**CON**, 10^3 spermatozoa/mm^3), percentage of sperm motile (**MOT**, %), and morphologically abnormal cells (**ABN**, %). Heritability estimates for VOL, CON,

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MOT, and ABN range from 0.14 to 0.25, 0.13 to 0.26, 0.05 to 0.18, and 0.4 to 0.12, respectively (Grandjot et al., 1997a; Wolf, 2009, 2010). These estimates suggest that selection can improve semen traits of boars, leading to more units of usable semen (surpassing the minimum spermatozoa count for effective insemination) from an equal or reduced number of boars, potentially resulting in greater selection intensity and production efficiency in the swine industry (Smital et al., 2005; Oh et al., 2006; Foxcroft et al., 2008).

Despite genetic parameter estimates being available and the economic, health, and welfare benefits associated with the improvement of semen traits, no selection strategies that include semen traits have been developed; there has been no systematic study on the impact of selection programs that include these traits. Objectives of this study were to understand the impact of including semen traits in swine production systems and to identify the most effective integration of these traits into selection practices. Supporting aims were 1) to derive the economic values for the semen traits and 2) to evaluate the impact of including semen traits in 3- and 4-way crossbreeding schemes within a 3-tier system.

MATERIAL AND METHODS

Economic values of 4 semen traits, VOL, CON, MOT, and ABN and the number of usable semen doses per collection (**DOSES**) were developed for 3 selection strategies that also included traditional maternal and paternal traits. These strategies were applied to simulated 3- and 4-way crossbreeding schemes used in swine production and the resulting genetic gains were compared. A conventional AI technique was assumed.

The trait VOL is the volume of the sperm-rich fraction and ranges between 140 and 300 mL depending on the age and breed of the boar (Bidanel, 2011; Banaszewska and Kondracki, 2012). The trait CON is the concentration of spermatozoa in the collection (10^3spermatozoa/mm^3). With variability associated with age, breed, and number of collections per wk or collection frequency, estimates range between 300 and 650 × 10^3 spermatozoa/mm^3 (Smital et al., 2005; Banaszewska and Kondracki, 2012). The trait MOT is the percentage of all spermatozoa that appear to be active and moving progressively in a forward direction (Broekhuijse et al., 2012). The trait ABN is the percentage of spermatozoa that appear to be abnormal (Dominiek et al., 2011). Following industry standards, ejaculates are used for insemination when MOT > 70% and ABN < 30% (Smital et al., 2005; Ruiz-Sanchez et al., 2006).

The trait DOSES is a function of the 4 semen traits and has been proposed as a single indicator of boar fertility and a possible trait for selection (Smital et al., 2005):

$$DOSES = \{[VOL \times CON/1{,}000]\times[\mathrm{MOT}/100 \times (1-\{ABN/100\})]\}/SPD,$$

where spermatozoa per dose (**SPD**) is the number of spermatozoa per dose recommended for successful insemination (usable dose). This study assumed SPD = 3.0 × 10^9 spermatozoa/dose following the industry standard for conventional insemination practices (Safranski, 2008).

Selection Strategies

Three selection strategies were analyzed. Selection Strategy I (baseline or traditional strategy) encompassed genetic selection for maternal and paternal traits (NSIF, 2002; Gonzalez-Peña et al., 2014). Maternal traits included number of pigs born alive (**NBA**), litter birth weight (**LBW**), adjusted 21-d litter weight (**A21**) including linear and quadratic adjustments for litter age in d (litter weight*[2.218- 0.0811(age) + 0.0011(age)^2]; Wood et al., 1990), and number of pigs at 21 d (**N21**). Paternal traits included number of days to 113.5 kg (**D113**), backfat (**BF**), ADG (from 60 lb to 250 lb equivalent to 27 kg to 113.5 kg), feed efficiency (**FE**; feed:gain), and lean carcass % (**LEAN**). ADG and D113 were both included in the index in consideration that a number of paternal line selection strategies tend to prioritize D113 meanwhile a number of maternal line selection strategies tend to prioritize ADG. Also, both traits span non-completely overlapping periods in the productive life of pigs. ADG encompasses the period between 27 kg and 113.5 kg of BW, while D113 encompasses the period between birth and 113.5 kg of BW. Selection Strategy II included the traits from Strategy I and DOSES. Selection Strategy III included the traits from Strategy I and the 4 individual semen traits: VOL, CON, MOT, and ABN.

Table 1 lists the traits included in the selection indices, and the corresponding economic values ($/unit), phenotypic SD, heritability, and genetic and phenotypic correlation values. These values were compiled from a review of existing literature (NSIF, 2002; Smital et al., 2005). A selection index derived using the profit equation method that takes these covariations into account was utilized to maximize the genetic progress of all traits in the favorable direction. For example, the resulting selection index favors lower BF and higher FE without undesirable changes in ADG and LEAN.

Biological and Technological Input Parameters

Biological, technological, and financial input parameters used in the simulation were based on a literature review. Inputs for the 3-way crossbreeding scheme were obtained from previous studies of

Table 1. Economic value (EV), heritability (h^2), phenotypic standard deviation (s_p), genetic (above diagonal), and phenotypic (below diagonal) correlation values assumed for the traits included in the selection indices used in the nucleus and multiplier stages[1]

	Parameter			Correlation[3]													
Trait[2]	EV($)	h^2	s_p	NBA	LBW	A21	N21	D113	BF	FE	ADG	LEAN	VOL	CON	MOT	ABN	DOSES
NBA	13.50	0.10	2.50	***1.00***	0.63	0.12	0.80	0.20	0	0	0	0	-0.07	-0.02	0.04	-0.24	-0.10
LBW	0.45	0.29	7.20	0.80	***1.00***	0.50	0.67	0	0	0	0	0	0	0	0	0	0
A21	0.50	0.15	16.00	0.20	0.66	***1.00***	0.60	0	0	0	0	0	0	0	0	0	0
N21	6.00	0.06	2.35	0.60	0.70	0.6	***1.00***	0	0	0	0	0	-0.04	-0.02	-0.06	-0.15	0
D113	-0.12	0.30	13.00	0.10	0	0	0	***1.00***	0	0.60	-0.70	0.10	0	0	0	0	0
BF	-15.00	0.40	0.20	0	0.10	0	0	-0.18	***1.00***	0.33	0.14	0.70	0	0	0	0	0
FE	-13.00	0.30	0.25	0	0	0	0	0.50	0.25	***1.00***	-0.70	0.40	0	0	0	0	0
ADG	6.00	0.30	0.20	0	0.20	0	0	-0.50	0.20	-0.65	***1.00***	0.20	0	0	0	0	0
LEAN	1.10	0.48	1.50	0	0	0	0	0.10	0.70	0.30	0.10	***1.00***	0	0	0	0	0
VOL	TBE	0.25	91.86	0	0	0	0	0	0	0	0	0	***1.00***	-0.68	-0.04	-0.09	–
CON	TBE	0.18	144.92	0	0	0	0	0	0	0	0	0	-0.5	***1.00***	0.12	0.13	–
MOT	TBE	0.12	4.31	0	0	0	0	0	0	0	0	0	0.01	0.04	***1.00***	-0.48	–
ABN	TBE	0.10	5.75	0	0	0	0	0	0	0	0	0	-0.01	0.03	-0.20	***1.00***	–
DOSES	TBE	0.40	10.70	0	0	0	0	0	0	0	0	0	x	x	x	–	***1.00***

[1]Values were compiled from NSIF (2002) and Smital et al. (2005).

[2]NBA = number born alive (pigs/litter); LBW = litter birth weight (lb; 1 lb = 2.2046 kg); A21 = adjusted 21-d litter weight, adjusted for the age of the litter (lb); N21 = number of pigs per litter at 21 d (pigs/litter); D113 = days for pig to reach 113.5 kg (d); BF = backfat (in; 1 in = 25.4 mm); FE = feed efficiency (lb feed/lb gain); ADG = average daily gain (lb/day) between 60 lb and 250 lb; LEAN = carcass lean (%); VOL = semen volume (mL); CON = semen concentration (10^3 spermatozoa/mm^3); MOT = progressive motion of spermatozoa (%); ABN = abnormal spermatozoa (%); DOSES = number of usable semen doses per collection.

[3]- = Not applicable.

TBE = to be estimated.

similar swine production systems (Rutten et al., 2000; Gonzalez-Peña et al., 2014). Similar methodology was adapted to compute the input parameters for the 4-way crossbreeding scheme. Assumed input costs associated with boar maintenance and semen doses collected (e.g., facilities, management, collection costs) are presented in Table 2 (Rutten et al., 2000; Dhuyvetter et al., 2009). The number of collection per wk considered in this study ranged from 1 to 7 (corresponding to 7-d to 1-d intervals between collections). This range considers the physiological limitation of a boar to produce more than 16×10^9 spermatozoa per d from both testes (Senger, 1997) and industry practices. Following previous studies of semen traits, a linear relationship between number of collections per wk and VOL, CON, ABN, and MOT was assumed (Rutten et al., 2000). For comparison purposes and set barn capacity, all strategies were simulated to result in 225,000 farrowings at the commercial level every 6 mo and a planning horizon of 10 yr (Weller, 1994; Gonzalez-Peña et al., 2014). This farrowing number adjusted by the 2.25 expected farrowings/year (2.25/2), corresponding to 200,000 sows/cycle in a system that uses conventional AI with liquid extended semen (fresh semen preparation), has an average farrowing rate of 85%, and produces on average 10 live pigs/litter (USDA, 2007; PigCHAMP, 2011; Knox et al., 2013).

Table 2. Costs and financial input values assumed[1]

Variable	Input
Interest rate	2.00%
Insurance costs	$24,039.80
Maintenance and repair costs	$60,099.00
Cost associated with the reproduction technology	$ 12.75
Cost of boar maintenance and semen processing per collection frequency	
Fixed costs/boar space/wk	
Facilities	$6.30
Feed	$3.00
Utilities	$0.20
Miscellaneous health costs	$0.40
Cost/collection	
Labor	$6.30
Laboratory supplies	$5.50
Semen sale price	$6.00
Cost/semen dose	
Semen extender	$0.20
Bags and equipment	$0.20
Labor (post semen evaluation)	$0.17
Boar costs per semester assuming:	
7.00 collections/wk; (17.6 usable doses/collection)	$4,230.82
3.50 collections/wk (19.2 usable doses/collection)	$2,327.10
2.33 collections/wk (23.5 usable doses/collection)	$1,785.90
1.75 collections/wk (25.3 usable doses/collection)	$1,450.46
1.40 collections/wk (25.7 usable doses/collection)	$1,220.14
1.17 collections/wk (26.2 usable doses/collection)	$1,068.33
1.00 collection/wk (27.3 usable doses/collection)	$968.79

[1]Values were compiled from Rutten et al. (2000) and Dhuyvetter et al. (2009).

Derivation of the Economic Values

A profit equation adapted from an established economic system was developed for the traits (Rutten et al., 2000; Smital et al., 2005). A profit function is an equation that models the change in net economic returns as a function of a series of biological and economic parameters. The economic value of a trait was computed as the first partial derivative of the financial indicator evaluated at the population mean for all traits. The use of partial derivatives of the profit function method circumvents double counting of traits (Dekkers, 2005). The net profit were

$$P = \mathrm{R} - \mathrm{C},$$

where P denotes the profit per boar space, R denotes the returns per boar space, C denotes the costs per boar space, and the terms were expressed on a per wk basis.

Returns per boar space depend on the DOSES corresponding to the number of collections per wk (*N*) and the semen sale price (*S,* \$/dose):

$$R = \mathrm{DOSES} \times \mathrm{S} \times \mathrm{N}.$$

The costs per boar space were given by

$$\mathrm{C = F + CC \times N + CD \times N \times DOSES},$$

where F denotes the fixed costs per boar space including facility, feed, utilities, and health management per wk; CC denotes the costs per collection including labor and laboratory supplies; and CD is the costs per dose including extender, equipment, and post evaluation labor (Table 2).

Partial derivatives of the profit function, taken with respect to each trait of interest (VOL, CON, MOT, ABN, or DOSES at the corresponding *N*), were used to compute the economic value for each semen trait. The partial derivative for VOL was

$$\frac{\partial P}{\partial VOL} = \frac{CON \times MOT \times \left(1 - \left(\frac{ABN}{100}\right)\right) \times S \times N}{SPD \times 10^5} - \frac{CD \times CON \times MOT \times \left(1 - \left(\frac{ABN}{100}\right)\right) \times N}{SPD \times 10^5}.$$

The partial derivative for CON was

$$\frac{\partial P}{\partial CON} = \frac{VOL \times MOT \times \left(1 - \left(\frac{ABN}{100}\right)\right) \times S \times N}{SPD \times 10^5} - \frac{CD \times VOL \times MOT \times \left(1 - \left(\frac{ABN}{100}\right)\right) \times N}{SPD \times 10^5}.$$

The partial derivative for MOT was

$$\frac{\partial P}{\partial MOT} = \frac{VOL \times CON \left(1 - \left(\frac{ABN}{100}\right)\right) \times S \times N}{SPD \times 10^5} - \frac{CD \times VOL \times CON \times \left(1 - \left(\frac{ABN}{100}\right)\right) \times N}{SPD \times 10^5}.$$

The partial derivative for ABN was

$$\frac{\partial P}{\partial ABN} = \frac{CD \times VOL \times CON \times MOT \times N}{SPD \times 10^7} - \frac{VOL \times CON \times MOT \times S \times N}{SPD \times 10^7}.$$

Assuming

$$P = DOSES \times S \times N - [F + CC \times N + CD \times N \times DOSES],$$

the partial derivative for DOSES was

$$\frac{\partial P}{\partial DOSES} = S \times N - CD \times N.$$

Crossbreeding Schemes

The impact of the 3 selection strategies was evaluated for 2 crossbreeding schemes in a 3-tier production system. These schemes included 3 and 4 crosses between swine lines or breeds. The 3-way crossbreeding scheme included 2 maternal lines, A and B, and 1 paternal line C. In the 3-tier system, each nucleus line had 500 sows, the multiplier level produced F_1 sows from B boars and A sows, and at the commercial level, pigs obtained from the cross between F_1 BA sows and C boars were sold (Gonzalez-Peña et al., 2014). The 4-way scheme encompassed the 3-way scheme and an additional parental nucleus line D that had 500 sows. The multiplier level produced F_1 sows from B boars and A sows and F_1 DC boars from D boars and C sows; the commercial pigs obtained from the cross between F_1BA sows and F_1DC boars were sold. In both schemes, all maternal and paternal traits were included in the selection indices. However, maternal lines were selected mainly for female reproductive traits, and paternal lines C and D were selected mainly for growth-carcass and semen traits by means of selection index. Based on previous studies (Rutten et al., 2000; Smital et al., 2005), the number of semen collections per wk used to inseminate the F_1 sows considered in this study ranged from 1 to 7 collections/wk. The 3-way scheme was simulated using a transmission matrix including 16 population groups (Gonzalez-Peña et al., 2014). A novel transmission matrix including 22

Table 3. Transmission matrix depicting the relationship between the 22 pig selection groups in the simulated 3-tier, 4-way crossbreeding production system

		Maternal lines				Paternal lines				F1	F1
		A		B		C		D		DC	BA
Tier and group		Boars	Sows	Boars	Sows	Boars	Sows	Boars	Sows	Boars	Sows
Nucleus maternal line A	Boars	1	2								
	Sows	3	4								
Nucleus maternal line B	Boars			5	6						
	Sows			7	8						
Nucleus paternal line C	Boars					9	10				
	Sows					11	12				
								13	14		
								15	16		
Multiplier	Boars						17[3]	18[4]			
Multiplier	Sows		19[1]	20[2]							
Commercial										21[5]	22[6]

[1]Sows in group 19 are the offspring of line A boars and sows (groups 1, 2, 3, and 4).

[2]Boars in group 20 are the offspring of line B boars and sows (groups 5, 6, 7, and 8).

[3]Sows in group 17 are the offspring of line C boars and sows (groups 9, 10, 11, and 12).

[4]Boars in group 18 are the offspring of line D boars and sows (groups 13, 14, 15, and 16).

[5]Boars in group 21 are the offspring of group 17 sows and group 18 boars.

[6]Sows in group 22 are the offspring of group 19 sows and group 20 boars. The sows in group 22 were inseminated using conventional insemination technique with fresh semen from boars in group 21 to produce pigs for the market.

population groups was developed to simulate the 4-way scheme (Table 3; Wünsch et al., 1998).

Evaluation of the Genetic Trend and the Relative Economic Value

Genetic improvement that results from considering semen traits in breeding and selection decisions was evaluated across strategies (3 strategies × 2 crossbreeding schemes = 6 combinations). The selection strategy (Strategy I, II, or III) and crossbreeding scheme (3- or 4-way) combinations were denoted as I3, II3, III3, I4, II4, and III4. For the 3-way scheme, selection indices were developed to select replacement boars and sows in the nucleus lines and F_1 BA sows that were inseminated with line C semen. Additional selection indices were developed in the 4-way scheme to select nucleus line D boars and sows and F_1 DC boars. While Strategy I includes maternal and paternal traits, Strategy II also includes DOSES, and Strategy III includes all 4 semen traits. The economic values ($/unit) were based on National Swine Improvement Federation guidelines (NSIF, 2002). For the maternal lines, females at the nucleus level were selected based on the own performance for maternal traits and the parental and half-sib performance for maternal traits; at the multiplier level, females were selected based on the parental and half-sib performance for maternal traits; and at the commercial level, females were selected based on the parental performance for maternal traits. For the maternal lines, males at the nucleus level were selected based on the parental, full, and half-sib performance for maternal traits and the male's own performance for paternal traits; at the multiplier level, males were selected based on the parental performance for maternal and paternal traits and full and half-sib performance for maternal traits; and at the commercial level, males were selected based on the parental performance for all traits. For the paternal lines, females at the nucleus level were selected based on the parental and half-sib performance for paternal traits and based on the female's own performance for the maternal traits; at the multiplier level, females were selected based on the parental performance for maternal and paternal traits and based on half-sib performance for paternal traits; and at the commercial level, females were selected based on the parental performance for paternal and maternal traits. For the paternal lines, males at the nucleus level were selected based on the male's own performance for paternal traits and parental, full, and half-sib performance for all traits; at the multiplier level, males were selected based on the parental performance for all traits and full and half-sib performance for maternal traits; and at the commercial level, males were selected based on the parental performance for parental traits.

The relative economic value for each trait in the selection indices within strategy-scheme combination was the product of the economic value multiplied by the standard discount expression (to adjust for interest rate across time) at discount factor 0.744, expressed relative to the genetic standard deviation of each trait (Nitter et al., 1994). One round of selection (selection based on own phenotype, parental, and half-sib information) was used, and thus the effects of inbreeding, reduced lower genetic variation due to selection, and return from breeding product sales were assumed to be negligible (Wünsch et al., 1999; Willam et al., 2008; Gonzalez-Peña et al., 2014). The economic values estimated for the semen traits were integrated into the selection strategies and applied to the 3-tier system that was simulated using the software ZPLAN (Willam et al., 2008). This software supports the assessment of genetic and financial progress in a deterministic framework using selection indices and gene flow methodology (Willam et al., 2008).

RESULTS AND DISCUSSION

Seedstock producers at the nucleus level of a 3-tier swine production system traditionally select boars for maternal (mostly sow fertility) or paternal (mostly growth, carcass, and meat quality) traits. However, superior genetics for maternal or paternal traits are ineffective when boars cannot produce usable semen in adequate quantity to transmit the favorable genes to the offspring. Despite the positive correlation between boar fertility and the rate of genetic improvement, semen traits associated with boar fertility are usually omitted from selection decisions (Rothschild, 1996; Robinson and Buhr, 2005; Foxcroft et al., 2008).

In addition to being key for achieving high selection intensity, semen traits provide information on reproductive performance complementary to pregnancy rate and litter size born (Robinson and Buhr, 2005; Foxcroft et al., 2008). Significant correlations between semen motility and morphology and farrowing rates and litter size have been reported (Waberski et al., 2011; Broekhuijse et al., 2012; Kummer et al., 2013). Heritability estimates for VOL, CON, and MOT from 3 German genetic lines ranged from 0.14 to 0.18, 0.17 to 0.26, and 0.05 to 0.18, respectively (Grandjot et al., 1997a). Similar heritability values for VOL, CON, and MOT ranging from 0.14 to 0.25, 0.13 to 0.23, and 0.06 to 0.16, respectively, were estimated from 7 crossbred pig populations in the Czech Republic (Wolf, 2009). In Czech Large White and Landrace populations, the heritability estimates for VOL, CON, MOT, and ABN were between 0.20 and 0.25, 0.18 and 0.18, 0.08 and 0.12, and 0.10 and 0.12, respectively (Wolf, 2010). Greater heritability estimates for VOL, CON, MOT, and DOSES (0.58, 0.49, 0.38, 0.34, and 0.40, respectively) were obtained in a data set derived from 19 purebred and crossbred populations using mean values per boar instead of individual ejaculate measurements (Smital et al., 2005). Estimates of genetic correlations between NBA and VOL, CON, MOT, and ABN ranged from −0.07 to −0.22, −0.02 to 0.11, 0.04 to 0.24, and −0.24 to −0.06, respectively (Grandjot et al., 1997b; Smital et al., 2005; Wolf, 2010). Although the heritability estimates imply that selection for semen traits will result in genetic gains for these traits, the limited understanding of how to integrate these traits with traditional maternal and paternal traits in selection decisions has hampered genetic progress. This study provided insights on 2 major components of genetic improvement for semen traits: economic values and genetic gains from strategies incorporating 4 semen traits or number of semen doses, a function of the previous traits. Additional insights were gained from the consideration of 2 crossbreeding schemes and a range of semen collection frequencies per wk.

The impact of the different selection schemes on the traits is due to the indirect relationships between traits. Table 1 shows that the semen traits are only related to NBA and N21. Since D113 is correlated to NBA, only changes in NBA directly influences D113. However, other traits such as ADG are not correlated to NBA but are correlated to D113. This results in a relatively higher indirect response in D113 compared to ADG in the selection strategies involving semen traits.

Economic Values of Semen Traits

Economic values are listed in Table 4. Economic values and relative economic values for a range of semen collections per wk were estimated based on reported boar semen trait averages (VOL = 237.2 mL, CON = $412.6 \times 10^3/\text{mm}^3$, MOT = 80.5%, ABN = 7.6%; Smital et al., 2005) and associated costs (Table 4). The economic values for VOL, CON, MOT, ABN, and DOSES increased in absolute terms with decreasing collection frequency from \$0.21 to \$1.44/mL, \$0.12 to \$0.83/(10^3/mm^3), \$0.61 to \$12.66/%, −\$0.53 to −\$10.88/%, and \$2.01 to \$41.43/dose. The trend of more extreme economic values for VOL, CON, MOT, ABN, and DOSES with higher number of collections per wk can be explained by changes in the quantity of usable semen available (Table 4). The greater number of collections per wk decreased the number of doses per ejaculate and resulted in reduced economic values. These results are consistent with reports that more frequent semen collections are associated with fewer spermatozoa being accumulated in the epididymal reserves (Rutten et al., 2000; Frangež et al., 2005). Consistent with the assumed relationship between semen traits and number of collections per wk, the economic value of these traits was more extreme with fewer collections per wk associated with the lower number of usable doses (above the minimum number of spermatozoa) per wk (Rutten et al., 2000). Limited reports on genetic and economic considerations of boar semen traits contribute to the variability in the economic values and impact the robustness of the profit equation (Knap, 2005). The derivation and estimation of economic values for semen traits constitute an initial effort toward understanding the impact of including semen traits in selection decisions.

Genetic Gains for Maternal, Paternal, and Semen Traits

The average genetic gain (Table 5) for the maternal traits NBA, LBW, A21, and N21 remained fairly constant across strategy-scheme combinations. Inclusion of boar semen traits in the selection indices, individually or combined in DOSES, had a minor impact on the genetic gains for maternal traits. The difference in genetic gain between selection Strategy I that excluded semen traits and the average of Strategies II and III (including semen traits or DOSES, respectively) ranged from 5.4% to 7.7%. The low impact of including boar semen traits in the selection indices on the genetic gain for maternal traits is due to the low genetic correlation between these traits and the relatively low weight on semen traits in the indices used for the maternal lines.

Inclusion of semen traits in the selection indices impacted the genetic gain on the paternal traits. On average, genetic gains for paternal traits were greater in selection Strategy I followed by Strategies III and II across crossbreeding schemes (Table 5). Deterioration in genetic gains for paternal traits relative to Strategy I was substantially less (25% to 66%) in Strategy III including individual semen traits than in Strategy II including DOSES. For example, the greater improvement in BF occurred in selection Strategy I, followed by Strategy III and Strategy II for both crossbreeding schemes. Expressing the difference in BF gain between strategies relative to the gain in Strategy I [(II3-I3)/I3, (III3-I3)/I3, (II4-I4)/I4 or (III4-I4)/I4], the genetic gain for II3, III3, II4, and III4 was 59%, 26%, 68%, and 32%, respectively. These gains reflect the complex indirect relationships between semen traits and paternal traits due to the genetic correlations. Following the genetic correlations in Table 1, most semen traits are negatively correlated to NBA, NBA is positively correlated to D113, D113 is negatively correlated to ADG, and ADG is positively correlated to BF. The only difference between selection strategies is the semen traits; thus, the negative genetic correlation between NBA and most semen traits resulted in decreased genetic gain for

Table 4. Economic value from partial derivatives of the profit for the individual semen traits volume, concentration, motility and abnormalities, and DOSES per wk by collection schedule

	Collections/wk						
Trait[1]	7	3.5	2.33	1.75	1.4	1.17	1.00
Vol ($/mL)	0.21	0.41	0.62	0.82	1.03	1.23	1.44
Con ($/x10^{3}spermatozoa/mm^3)	0.12	0.24	0.35	0.47	0.59	0.71	0.83
Mot ($/%)	0.61	3.62	5.43	7.23	9.04	10.85	12.66
ABN ($/%)	−0.53	−2.63	−4.38	−6.04	−7.67	−9.28	−10.88
DOSES ($/dose)	2.01	10.00	16.67	23.00	29.20	35.34	41.43

[1]VOL = semen volume: CON = semen concentration; MOT = progressive motion of spermatozoa; ABN = abnormal spermatozoa; DOSES = number of usable insemination doses per collection.

Table 5. Annual genetic gain for individual traits by selection strategy and crossbreeding scheme

		Strategy and crossbreeding scheme[2]					
Trait[1]	Unit	I3	II3	III3	I4	II4	III4
NBA	pigs/litter	0.013	0.013	0.015	0.009	0.009	0.010
LBW	lb	0.229	0.249	0.236	0.194	0.220	0.192
A21	lb	0.143	0.132	0.139	0.123	0.110	0.121
N21	pigs/litter	0.009	0.009	0.008	0.008	0.007	0.008
D113	days	−0.103	0.153	0.093	−0.552	−0.091	−0.210
BF	in	−0.011	−0.005	−0.008	−0.016	−0.005	−0.011
FE	lb/lb	0.004	0.002	0.002	0.004	0.002	0.002
ADG	lb	0.002	−0.003	0.002	0.008	−0.0001	0.003
LEAN	%	0.032	0.005	0.013	0.068	0.020	0.042
DOSES	doses	–	1.229	–	–	1.846	–
VOL	mL	–	–	2.060	–	–	3.488
CON	x10^{3}spermatozoa/mm^3	–	–	−0.477	–	–	−0.652
MOT	%	–	–	0.023	–	–	0.030
ABN	%	–	–	0.013	–	–	0.005

[1]NBA = number born alive; LBW = litter birth weight (1 lb = 2.2046 kg); A21 = adjusted 21-d litter weight; N21 = number at 21 d; D113 = d for pig to 113.5 kg; BF = backfat (1 in = 25.4 mm); FE = feed efficiency; ADG = average daily gain; LEAN = carcass lean; VOL = semen volume; CON = semen concentration; MOT = progressive motion of spermatozoa; ABN = abnormal spermatozoa; DOSES = number of usable insemination doses per collection.

[2]Strategy: I = baseline; II = baseline + *DOSES*; III = baseline + *VOL* + *CON* + *MOT* + *ABN*; Crossbreeding scheme: 3- and 4-way = three/four-way crossbreeding scheme.

- = Not applicable

BF when using semen traits in an index. Similar trends were observed for D113, ADG, and LEAN.

The reduced impact of selection for boar semen traits on the genetic gain for paternal traits in the 4-way relative to the 3-way scheme was associated with the distribution of the effects between 2 parental lines (C and D) in 4-way scheme relative to the concentration of the effects in one parental line (C) in the 3-way scheme (Table 5). Similarly, the reduced impact of selection for boar semen traits on genetic gain for paternal growth in the selection Strategy III relative to Strategy II could be due to the distribution of the effects between 4 traits in Strategy III relative to the concentration of the effects in 1 trait (DOSES) in Strategy II.

The results summarized in Table 5 suggest that selection to improve semen traits could be implemented in maternal nucleus lines without substantial loss in genetic gain for the other traits. Also, selection for semen traits had less effect on the genetic gains for paternal traits when the 4 traits are included in the selection index relative to DOSES and in a 4-way scheme relative to a 3-way crossbreeding scheme. Simulation increasing the selection intensity as the result of the improvement of the semen traits and the efficient production of doses will be needed.

Results for standard maternal and paternal traits across scenarios were consistent with the ranges reported by other studies for most traits (Table 5). The genetic trends for BF, ADG, NBA, and LBW in female Large White pigs were −0.239 mm, 0.255 g, 0.028 pigs/litter, and 0.023 kg, respectively (de Almeida Torres et al., 2005). The genetic trends for FE, BF, and ADG in male Large White pigs were −0.012 kg, −0.235 mm, and 1.591 g, respectively (de Almeida Torres et al., 2005).

Genetic trends per year in Pietrain for ADG and FE were 1.33 and −0.011, respectively (Habier et al., 2009). An annual genetic trend in Large White pigs for NBA was 0.038 (Canario et al., 2005). The approximate annual genetic progress for NBA in American Yorkshire swine between 1983 and 1999 was reported at approximately 0.028, while the annual genetic trend for BF (cm) between 1994 and 1999 was −0.078 (See et al., 2001). Across studies and scenarios, genetic gain depends on the traits, selection, and culling practices; genetic parameters; and weights considered (Rodriguez-Zas et al., 2003; 2006). For the selection strategies evaluated, genetic gains for maternal traits (Table 5) were not affected by the inclusion of semen traits. However, genetic gains for paternal growth and carcass traits were reduced when semen traits were included in the selection indices. The rationale for this trend is that selection was based on their own phenotype, parental, and half-sib information, and in the paternal lines, the boars have more direct information for semen traits that compete with information from the paternal traits in the selection index. Our results demonstrated that simultaneous genetic gains for semen traits are possible without detrimental effects on the genetic gains for maternal traits.

Relative Economic Values of Maternal, Paternal, and Semen Traits

The relative economic value for each trait was computed as the product of the economic value multiplied by the standard discount expression (to adjust for interest rate across time), expressed relative to the genetic standard deviation of each trait (%). The relative economic values for each strategy-scheme combination are presented in Tables 6 and 7 for 1 (weekly collection), 2.33 (one collection every 3 d), and 7 (daily collection) collections/wk. These values measure the relative importance of each trait in the selection index (Wünsch et al., 1999; Gonzalez-Peña et al., 2014). The trait NBA dominated the index for the maternal lines (A and B), and BF and FE dominated the index for the paternal lines.

The relative economic values of paternal (e.g., growth, feed efficiency) and maternal (e.g., litter size) traits dominate those for semen traits. A comparison of the behavior of the 4 semen traits relative to DOSES was undertaken. The sum of the relative economic values for the 4 semen traits in Strategy III was 70% (maternal nucleus lines) to 78% of the economic value for DOSES in Strategy II across crossbreeding schemes (Tables 6 and 7). However, the relationship between the sum of relative economic values for the 4 semen traits and the economic value for DOSES was not linear across the number of semen collections per wk. The decrease in the relative economic values of semen traits and DOSES with higher number of collections per wk was sharper between 1 and 2.33 collections/wk than between 2.33 and 7 collections/wk. This nonlinear pattern is also observed in the sharper increase in total number of usable doses per wk between 1 and 2.33 collections/wk than between 2.33 and 7 collections/wk (Table 2). This suggests that the changes in economic values are dominated by the number of usable doses per wk primarily through the *CD* relative to the *CC*.

The relationship between maternal and paternal sum of relative economic value within nucleus line was consistent across strategies within collection per wk schedule (Tables 6 and 7). The ratio between maternal and paternal sum of relative economic values was consistent for lines A, B (3- and 4-way schemes) and D (4-way scheme) across collection schedules. The maternal:paternal trait relative economic value ratio for lines A, B, and D in the 4-way scheme averaged 0.71, 1.29, and 0.008, respectively, and for lines A and B in the 3-way scheme averaged 0.80 and 1.26. However, the maternal:paternal relative

Table 6. Relative economic values of the traits in the selection indices used in the maternal (A and B) and paternal (C) nucleus lines in the 3-way crossbreeding scheme for selected number of semen collections per wk (7 = daily collection; 2.33 = 1 collection every 3 d; and 1 = weekly collection) by selection strategy[1]

	7 collections/wk by Strategy[3]								
	I3			II3			III3		
Trait[2]	A	B	C	A	B	C	A	B	C
NBA	29.39	36.86	0.30	28.49	35.96	0.28	28.73	36.20	0.29
LBW	0.98	1.23	0.01	0.95	1.20	0.01	0.96	1.21	0.01
A21	1.09	1.37	0.01	1.06	1.33	0.01	1.06	1.34	0.01
N21	13.06	16.38	0.13	12.66	15.98	0.13	12.77	16.09	0.13
D113	0.19	0.15	0.34	0.18	0.15	0.32	0.18	0.15	0.33
BF	23.63	18.81	42.40	22.90	18.34	40.12	23.09	18.47	40.71
FE	20.48	16.30	36.74	19.85	15.90	34.77	20.01	16.00	35.28
ADG	9.45	7.52	16.96	9.16	7.34	16.05	9.24	7.39	16.28
LEAN	1.73	1.38	3.11	1.68	1.35	2.94	1.69	1.35	2.99
DOSES	–	–	–	3.07	2.46	5.38	–	–	–
VOL	–	–	–	–	–	–	0.32	0.26	0.57
CON	–	–	–	–	–	–	0.18	0.15	0.33
MOT	–	–	–	–	–	–	0.94	0.75	1.66
ABN	–	–	–	–	–	–	0.82	0.65	1.44
	2.33 collections/wk by Strategy								
	A	B	C	A	B	C	A	B	C
NBA	29.38	36.83	0.46	23.26	30.46	0.31	25.11	32.44	0.35
LBW	0.98	1.23	0.02	0.78	1.02	0.01	0.84	1.08	0.01
A21	1.09	1.36	0.02	0.86	1.13	0.01	0.93	1.20	0.01
N21	13.06	16.37	0.21	10.34	13.54	0.14	11.16	14.42	0.16
D113	0.19	0.15	0.34	0.15	0.12	0.23	0.16	0.13	0.26
BF	23.64	18.83	42.29	18.72	15.57	28.77	20.21	16.58	32.43
FE	20.49	16.32	36.65	16.22	13.49	24.93	17.51	14.37	28.11
ADG	9.45	7.53	16.92	7.49	6.23	11.51	8.08	6.63	12.97
LEAN	1.73	1.38	3.10	1.37	1.14	2.11	1.48	1.22	2.38
DOSES	–	–	–	20.80	17.30	31.97	–	–	–
VOL	–	–	–	–	–	–	0.84	0.69	1.34
CON	–	–	–	–	–	–	0.47	0.39	0.76
MOT	–	–	–	–	–	–	7.31	6.00	11.74
ABN	–	–	–	–	–	–	5.90	4.84	9.47
	1 collection/wk by Strategy								
	A	B	C	A	B	C	A	B	C
NBA	29.39	36.86	0.75	17.78	24.26	0.35	20.89	27.85	0.44
LBW	0.98	1.23	0.03	0.59	0.81	0.01	0.70	0.93	0.01
A21	1.09	1.37	0.03	0.66	0.90	0.01	0.77	1.03	0.02
N21	13.06	16.38	0.33	7.90	10.78	0.15	9.29	12.38	0.19
D113	0.19	0.15	0.34	0.11	0.10	0.16	0.13	0.11	0.20
BF	23.63	18.81	42.10	14.30	12.38	19.47	16.80	14.21	24.42
FE	20.48	16.30	36.49	12.39	10.73	16.87	14.56	12.32	21.16
ADG	9.45	7.52	16.84	5.72	4.95	7.79	6.72	5.68	9.77
LEAN	1.73	1.38	3.09	1.05	0.91	1.43	1.23	1.04	1.79
DOSES	–	–	–	39.49	34.19	53.77	–	–	–
VOL	–	–	–	–	–	–	1.61	1.36	2.34
CON	–	–	–	–	–	–	0.93	0.79	1.35
MOT	–	–	–	–	–	–	14.18	11.99	20.61
ABN	–	–	–	–	–	–	12.18	10.31	17.71

[1]Relative economic value = economic value * standard discount expression expressed relative to the genetic standard deviation.

[2]NBA = number born alive; LBW = litter birth weight; A21 = adjusted 21-d litter weight; N21 = number of pigs per litter at 21 d; D113 = days for pig to reach 113.5 kg; BF = backfat; FE = feed efficiency; ADG = average daily gain; LEAN = carcass lean; VOL = semen volume; CON = semen concentration; MOT = percentage of all spermatozoa that are active with progressive motion; ABN = percentage of abnormal spermatozoa; DOSES = number of usable insemination doses per collection.

[3]Strategy: I = baseline; II = baseline + DOSES; III = baseline + VOL + CON + MOT + ABN. – = Not applicable

Table 7. Relative economic values of the traits in the selection indices used in the maternal (A and B) and paternal (C and D) nucleus lines for the 4-way crossbreeding scheme for selected number of semen collections per wk (7 = daily collection; 2.33 = 1 collection every 3 d; and 1 = weekly collection) by selection strategy[1]

	7 collections/wk by Strategy[3]											
	I4				II4				III4			
Trait[2]	A	B	C	D	A	B	C	D	A	B	C	D
NBA	27.40	37.13	0.68	0.53	26.51	36.22	0.64	0.50	26.75	36.46	0.65	0.51
LBW	0.91	1.24	0.02	0.02	0.88	1.21	0.02	0.02	0.89	1.22	0.02	0.02
A21	1.01	1.38	0.03	0.02	0.98	1.34	0.02	0.02	0.99	1.35	0.02	0.02
N21	12.18	16.50	0.30	0.24	11.78	16.10	0.28	0.22	11.89	16.21	0.29	0.23
D113	0.20	0.15	0.34	0.34	0.19	0.15	0.32	0.32	0.19	0.15	0.32	0.32
BF	24.91	18.64	42.15	42.25	24.11	18.18	39.90	39.98	24.32	18.30	40.48	40.57
FE	21.59	16.15	36.53	36.62	20.89	15.76	34.58	34.65	21.08	15.86	35.08	35.16
ADG	9.97	7.45	16.86	16.90	9.64	7.27	15.96	15.99	9.73	7.32	16.19	16.23
LEAN	1.83	1.37	3.09	3.10	1.77	1.33	2.93	2.93	1.78	1.34	2.97	2.98
DOSES	-	-	-	-	3.23	2.44	5.35	5.36	-	-	-	-
VOL	-	-	-	-	-	-	-	-	0.34	0.26	0.57	0.57
CON	-	-	-	-	-	-	-	-	0.19	0.15	0.32	0.32
MOT	-	-	-	-	-	-	-	-	0.99	0.74	1.65	1.65
ABN	-	-	-	-	-	-	-	-	0.86	0.65	1.43	1.43
	2.33 collections/wk by Strategy[2]											
	A	B	C	D	A	B	C	D	A	B	C	D
NBA	27.39	37.13	0.94	0.53	21.45	30.76	0.64	0.36	23.23	32.74	0.72	0.41
LBW	0.91	1.24	0.03	0.02	0.71	1.03	0.02	0.01	0.77	1.09	0.02	0.01
A21	1.01	1.38	0.03	0.02	0.79	1.14	0.02	0.01	0.86	1.21	0.03	0.02
N21	12.17	16.50	0.42	0.24	9.53	13.67	0.29	0.16	10.32	14.55	0.32	0.18
D113	0.20	0.15	0.34	0.34	0.16	0.12	0.23	0.23	0.17	0.13	0.26	0.26
BF	24.92	18.64	41.98	42.25	19.52	15.44	28.63	28.75	21.14	16.44	32.25	32.41
FE	21.60	16.15	36.39	36.61	16.91	13.38	24.81	24.92	18.32	14.24	27.95	28.09
ADG	9.97	7.45	16.79	16.90	7.81	6.18	11.45	11.50	8.45	6.57	12.90	12.96
LEAN	1.83	1.37	3.08	3.10	1.43	1.13	2.10	2.11	1.55	1.21	2.37	2.38
DOSES	-	-	-	-	21.69	17.16	31.81	31.95	–	–	–	–
VOL	-	-	-	-	-	-	-	-	0.87	0.68	1.33	1.34
CON	-	-	-	-	-	-	-	-	0.49	0.38	0.75	0.76
MOT	-	-	-	-	-	-	-	-	7.65	5.95	11.68	11.73
ABN	-	-	-	-					6.17	4.80	9.42	9.46
	1 collection/wk by Strategy[2]											
	A	B	C	D	A	B	C	D	A	B	C	D
NBA	27.40	37.11	1.13	0.53	16.23	24.50	0.52	0.24	19.18	28.10	0.66	0.31
LBW	0.91	1.24	0.04	0.02	0.54	0.82	0.02	0.01	0.64	0.94	0.02	0.01
A21	1.01	1.37	0.04	0.02	0.60	0.91	0.02	0.01	0.71	1.04	0.02	0.01
N21	12.18	16.50	0.50	0.24	7.21	10.89	0.23	0.11	8.52	12.49	0.29	0.14
D113	0.20	0.15	0.33	0.34	0.12	0.10	0.16	0.16	0.14	0.11	0.19	0.20
BF	24.91	18.65	41.86	42.25	14.76	12.31	19.41	19.50	17.44	14.12	24.33	24.46
FE	21.59	16.16	36.28	36.61	12.79	10.67	16.83	16.90	15.11	12.23	21.09	21.20
ADG	9.97	7.46	16.74	16.90	5.90	4.92	7.77	7.80	6.98	5.65	9.73	9.79
LEAN	1.83	1.37	3.07	3.10	1.08	0.90	1.42	1.43	1.28	1.04	1.78	1.79
DOSES	-	-	-	-	40.76	33.99	53.62	53.85	–	–	–	–
VOL	-	-	-	-	-	-	-	-	1.67	1.36	2.34	2.35
CON	-	-	-	-	-	-	-	-	0.96	0.78	1.35	1.35
MOT	-	-	-	-	-	-	-	-	14.72	11.91	20.54	20.65
ABN	-	-	-	-	-	-	-	-	12.65	10.24	17.65	17.74

[1]Relative economic value = economic value * standard discount expression expressed relative to the genetic standard deviation.

[2]NBA = number born alive; LBW = litter birth weight; A21 = adjusted 21-d litter weight; N21 = number of pigs per litter at 21 d; D113 = days for pig to reach 113.5 kg; BF = backfat; FE = feed efficiency; ADG = average daily gain; LEAN = carcass lean; VOL = semen volume; CON = semen concentration; MOT = percentage of all spermatozoa that are active with progressive motion; ABN = percentage of abnormal spermatozoa; DOSES = number of usable insemination doses per collection.

[3]Strategy: I = baseline; II = baseline + DOSES; III = baseline + VOL + CON + MOT + ABN.

- = Not applicable.

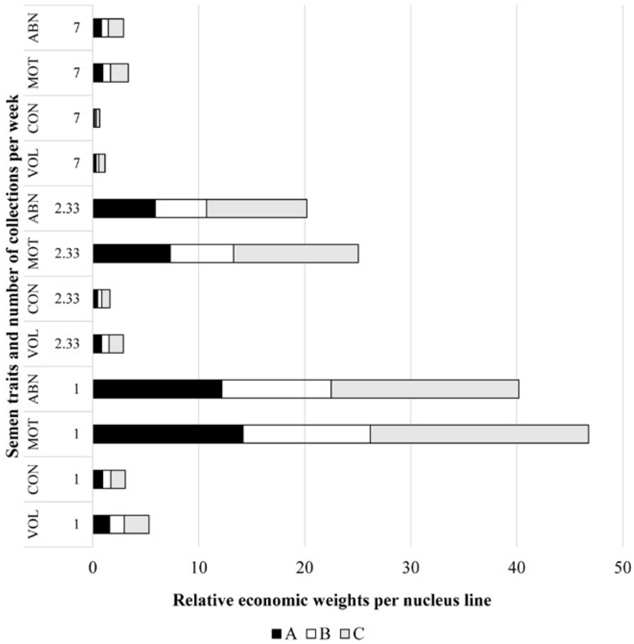

Figure 1. Relative economic values (%) of the 4 semen traits (VOLume, CONcentration, MOTility, and ABNormal) used in the selection indices for the maternal (A and B) and paternal (C) nucleus lines in Strategy III (baseline Strategy I + VOL + CON + MOT + ABN) for the 3-way crossbreeding scheme with 7, 2.33, and 1 semen collections/wk.

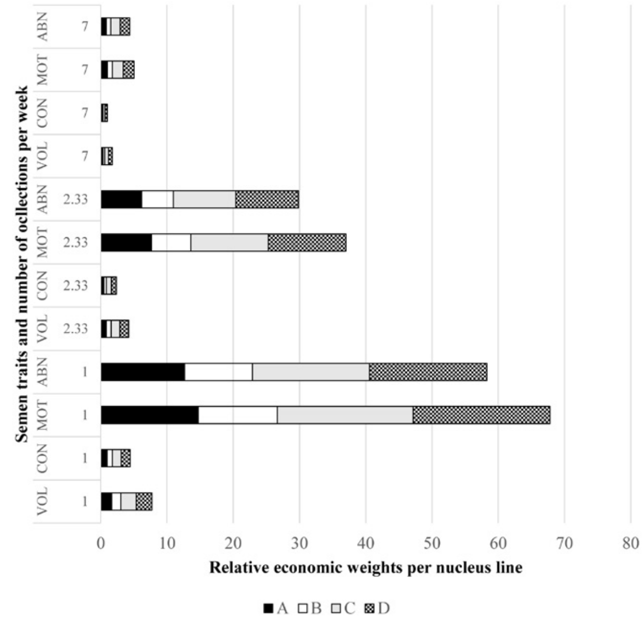

Figure 2. Relative economic values (%) of the 4 semen traits (VOLume, CONcentration, MOTility, and ABNormal) used in the selection indices for the maternal (A and B) and paternal (C and D) nucleus lines in Strategy III (Strategy I baseline + VOL + CON + MOT + ABN) for the 4-way crossbreeding scheme with 7, 2.33, and 1 semen collections/wk.

economic value ratio in line C increased with number of collections per wk from 0.010 to 0.017 and from 0.005 to 0.01 in the 4-way and 3-way schemes, respectively. The slight increase in maternal:paternal relative economic value ratio associated with higher collection schedules in line C that was not observed in line D could be due to the slightly lower relative economic values that the maternal traits received in line D relative to line C in the 3- and 4-way schemes.

Consistent with the trends presented in Table 4, the relative economic value of the semen traits and DOSES in the selection indices decreased with increasing collection frequency across crossbreeding schemes and strategies. On average, the relative economic value of the semen traits (sum of 4 traits or DOSES) increased 6.3-fold from 7 to 2.33 collections/wk and 1.9-fold from 2.33 to 1 collections/wk, and these trends were consistent across crossbreeding schemes (Tables 6 and 7). The trends for maternal lines were slightly higher and for paternal lines slightly lower than the average.

Simultaneous considerations of the trends in semen traits or DOSES relative economic values across collection schedules and across strategies offer insights into the interaction between these components (Tables 6 and 7). Despite the higher relative economic value of DOSES in Strategy II relative to the sum of the relative economic values of the 4 semen traits in Strategy III, the relative economic values of the 4 traits and DOSES exhibited a similar negative trend with number of collections per wk across strategies. The relative economic values reported in Table 7 also place the values presented in Table 4 in perspective. The range of economic values in Table 7 demonstrates that when considered in the context of all the traits studied, the relative economic value of the semen traits are modest and commensurate to the objectives of each line.

In both crossbreeding systems, the economic values for the semen traits VOL and CON remained low across number of collections per week; however, the economic value of MOT and ABN increased with lower collections per week, relative to the weight of paternal and maternal traits. The relative emphasis on MOT and ABN relative to traditional maternal and paternal traits at a low number of semen collections per wk could be associated with 2 phenomena. First, MOT and ABN have an increasingly large positive impact on profitability with fewer semen collections per week, but the low estimates of heritability and phenotypic standard deviation for MOT and ABN are low (Table 1). Under these conditions, the economic value increases as the number of semen collections per wk decreases. Second, MOT and ABN had low genetic correlation with any other maternal, paternal, or semen trait. Thus, the relative emphasis ensures progress on these traits with limited genetic variation on the time horizon considered with minimum negative impact on any of the other traits.

The relative economic values of the semen traits (Strategy III) in the nucleus population for the 3- and 4-way crossbreeding are presented in Fig. 1 and 2.

Consistent with the semen trait values assumed for all lines, the relative economic value of these traits in the selection indices remained constant across lines. The relative similarities between lines in the semen traits weights are in agreement with the planned line purpose. The values in paternal line C (and D) are slightly more similar to those in maternal line A than B. Congruent with the estimated economic values listed in Table 4, the absolute economic value of the semen traits is higher for 1 semen collection per wk relative to 7 collections per wk. This trend is consistent with the economic principle of assigning more weight to more rare events and the expectation that, for the range of collections considered in this study, more intense collection schedules results in higher total number of usable doses. The amount of useable doses per collection must be considered in relationship to the boar's physiology and the resting periods in semen collection. In practice, collection frequencies between 2.33 and 1.75/wk are favored based on total profitability (Rutten et al., 2000; Knox et al., 2008).

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