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Contribution of semen trait selection, artificial insemination technique, and semen dose to the profitability of pig production systems: A simulation study

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ABSTRACT

The economic impact of selection for semen traits on pig production systems and potential interaction with artificial insemination (AI) technique and semen dose remains partially understood. The objectives of this study were to compare the financial indicators (gross return, net profit, cost) in a three-tier pig production system under one of two selection strategies: a traditional strategy including nine paternal and maternal traits (S9) and an advanced strategy that adds four semen traits (S13). Maternal traits included the number of pigs born alive, litter birth weight, adjusted 21-day litter weight, and the number of pigs at 21 days, and paternal traits included days to 113.5 kg, back fat, average daily gain, feed efficiency, and carcass lean percentage. The four semen traits included volume, concentration, progressive motility of spermatozoa, and abnormal spermatozoa. Simultaneously, the impact of two AI techniques and a range of fresh refrigerated semen doses including cervical AI with 3×10^9 (CAI3) and 2×10^9 (CAI2) sperm cells/dose, and intrauterine AI with 1.5×10^9 (IUI1.5), 0.75×10^9 (IUI0.75), and 0.5×10^9 (IUI0.5) sperm cells/dose were evaluated. These factors were also evaluated using a range of farrowing rates (60%–90%), litter sizes (8–14 live-born pigs), and a selected semen collection frequency. The financial impact of the factors was assessed through simulation of a three-way crossbreeding system (maternal nucleus lines A and B and paternal nucleus line C) using ZPLAN. The highest return on investment (profit/cost) of boars was observed at 2.33 collections/wk (three periods of 24 hours between collections). Under this schedule, a significant ($P < 0.0001$) interaction between the selection strategy and the AI technique–dose combination was identified for the gross return; meanwhile, significant ($P < 0.0001$) additive effects of the selection strategy and AI technique–dose combination were observed for the net profit. The highest gross return was obtained under S13 with IUI0.75 and IUI0.5. The net profit of S13 was 34.37% higher than the traditional S9 ($P < 0.0001$). The net profit favored IUI0.5 with relative differences of 4.13%, 2.41%, 1.72%, and 0.43% compared to CAI3, CAI2, IUI1.5, and IUI0.75, respectively. The advanced selection strategy proposed including four semen traits is recommended on the basis of the higher profitability relative to the traditional strategy.

1. Introduction

Considerable genetic variation in sperm production and quality among boars has been reported, leading to recommendations for inclusion of semen traits in selection strategies for terminal sires [1]. In addition to genetic variability,

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economic, health, and welfare benefits associated with genetic improvement of semen traits have been noted [2–4]. Traditional semen traits such as ejaculate volume, sperm concentration, percentage of motile sperm, and morphologically abnormal cells are routinely measured and are helpful indicators of the boar's fertility [4–6]. The percentage of morphologically abnormal cells offers information on male organ maturity and functionality [6,7]; sperm concentration impacts the amount of doses obtained from one ejaculate [8], and ejaculate volume is critical for efficient use of lower-dose insemination techniques [9]. Traditional semen traits, albeit of variable phenotype [10] and correlation with fertility relative to modern indicators that rely on protein biomarkers, enable early detection of male reproductive disorders [11] associated with low boar fertility and stud efficiency [8,12,13]. Simulation studies suggest that strategies including semen traits in addition to traditional paternal (growth) or maternal (reproductive) traits can enable the maintenance or improvement of the former traits without compromising the genetic gains for the latter traits [14,15]. However, the impact of selection for semen traits on financial indicators of a pig production system has not been fully quantified. These traits are usually omitted from selection decisions, although evidence suggests that semen traits influence the financial returns of studs [5,16,17].

Studies of selection strategies including semen traits necessitate the simultaneous consideration of alternative artificial insemination (AI) techniques and associated semen dose required. Intrauterine semen deposition close to the oviduct using postcervical AI requires lower sperm dose and consequently fewer number of boars to produce the same number of insemination doses than conventional cervical insemination [18,19]. Thus, AI techniques that require lower doses and boars could potentially enable greater selection intensity, production efficiency, gross return, and net profit for the pig industry [2–4,20]. No study has assessed the simultaneous impact of selection for semen and traditional traits, AI technique, semen collection frequency, and semen dose on the financial indicators of a pig production system.

The objective of this study was to compare the economic impact of incorporating semen traits into a selection strategy relative to a traditional selection strategy under two AI techniques (cervical and intrauterine) that use fresh refrigerated semen across a number of sperm doses. Supporting aims were (1) to evaluate the return on investment for a range of semen collection frequencies and (2) to evaluate a set of complementary financial indicators under a range of productive and reproductive scenarios.

2. Materials and methods

The simultaneous economic impact on a crossbreeding pig production system of two selection strategies: traditional with nine traits (S9) and advanced adding four semen traits (S13); two AI techniques: cervical artificial insemination (CAI) or intrauterine insemination (IUI); and a number of sperm doses: two doses for CAI and three doses for IUI, was simulated and studied. A range of semen collection frequencies was considered, and the results were evaluated for a range of farrowing rate (FR) and litter size (LS) scenarios.

2.1. Selection strategies

A three-way crossbreeding scheme system including nucleus, multiplier, and production tiers was simulated using the software ZPLAN [21]. ZPLAN enables the simulation of breeding and selection plans using multitrait modeling, gene flow, and selection index methodology. The outputs include response to selection for every trait, and tier, annual genetic gains for breeding objective traits, and annual return on investment [21]. Briefly, the crossbreeding scheme included maternal lines A and B and paternal line C. Each nucleus line included 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 BA sows and C boars were sold [22]. The size of the simulated operation is comparable to others worldwide [23–26].

The traditional selection strategy studied [27] encompassed five maternal traits: number of pigs born alive, litter birth weight, adjusted 21-day litter weight, and number of pigs at 21 days, and four paternal traits: days to 113.5 kg, back fat, average daily gain, feed efficiency, and carcass lean percentage. The advanced selection strategy proposed added four semen traits: ejaculate volume, sperm concentration, percentage of motile sperm, and morphologically abnormal cells to the traditional strategy.

2.2. AI techniques and doses

The minimum fresh refrigerated semen dose required varies with the AI technique used. Thus, the economic impact of the selection strategy was studied for five combinations of the AI technique and semen dose. The AI technique–dose (expressed in sperm cells/dose) combinations evaluated included CAI and 3×10^9 (CAI3), CAI and 2×10^9 (CAI2), IUI and 1.5×10^9 (IUI1.5), IUI and 0.75×10^9 (IUI0.75), and IUI and 0.5×10^9 (IUI0.5). Frequently recommended and used doses for AI techniques are 3×10^9 sperm/dose for CAI and 1×10^9 sperm/dose for IUI [7,18]. Deviations from these doses impact the production efficiency [20].

For a 1-week (7 days) period per boar, a comprehensive series including seven resting intervals (RIs) between collections was evaluated. The RIs studied ranged between 1 and 7 days between collections and encompassed common practices [28]. Most studs use an RI of 5 to 7 days, followed by 3 to 4 days, and approximately 3% of the studs use an RI of 2 days. For completeness and to elucidate whether less-typical RI could be beneficial under particular selection strategies and AI technique–dose combinations, the RI of 1 to 7 days was studied.

Collection frequency (CF) was calculated as the ratio between the total period and the resting period (7/RI). A range of semen collection frequencies was considered. For RI = 1, 2, 3, 4, 5, 6, and 7 days, then CF = 7, 3.5, 2.33, 1.75, 1.4, 1.16, and 1, respectively, and the corresponding number of collections per 6 months is 168, 84, 56, 42, 34, 28, and 24, respectively. The number of doses available by CF and AI technique–dose combinations studied and the average usable doses per CF are summarized in Table 1. The CAI3 was considered baseline, and the values were multiplied by the standard sperm