



DOI 10.32900/2312-8402-2025-133-93-107

UDC 636.4:636.082.453, 519.23

THE META-ANALYSIS OF CERVICAL AND POST-CERVICAL ARTIFICIAL INSEMINATION OF SOWS

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The efficiency of artificial insemination (AI) in pig breeding plays a critical role in improving reproductive performance, reducing breeding costs, and increasing the sustainability of the pig farming industry. Unlike cervical insemination (CAI), PCAI allows for more precise sperm deposition in the uterus, improving the chances of conception and this ensures more effective intensive boar management.

To evaluate the effectiveness of PCAI in improving pig breeding efficiency, a meta-analysis was conducted using Jamovi software and algorithms from the metaphor package (R). Publication bias estimation was integrated into the analysis to ensure the reliability of the findings. The meta-analysis compared PCAI and CAI across three critical reproductive parameters: farrowing rate, fecundity index, and litter size. Criteria for study inclusion were defined to ensure the integrity of the analysis: the exclusion of studies involving exogenous hormonal treatments that could interfere with natural reproductive processes, the inclusion of studies with at least 20 animals per group, availability of group sizes and insemination doses, and provision of relevant variation statistics.

A total of 34 studies were included in the analysis for the farrowing rate, 33 studies for the fecundity index, and 33 studies for the litter size. The inclusion of such a large number of studies enhanced the robustness of the meta-analysis and allowed for a comprehensive evaluation of PCAI's impact on pig breeding efficiency.

The meta-analysis results showed that PCAI does not significantly worsen the farrowing rate. Specifically, the average log odds ratio based on the random-effects model was 0.0061 (95% CI: -0.2042 to 0.2163), indicating no detrimental effect on the farrowing rate when PCAI was used. Similarly, no significant differences were found between PCAI and CAI for the fecundity index (average standardized mean difference was 0.1156; 95% CI: -0.0790 to 0.3103), nor for litter size (average standardized mean difference was 0.0226; 95% CI: -0.0670 to 0.1123). These findings suggest that PCAI is comparable to traditional AI methods in terms of key reproductive parameters, which is a crucial consideration for breeders seeking to improve their production efficiency.

The publication showed that use of PCAI can offer several economic benefits. By increasing the efficiency of boars and making desirable genetics more accessible, PCAI reduces the need for maintaining a large number of boars on farms. This not only reduces the costs associated with keeping boars, but also promotes the wider use of high-quality genetic material, leading to the genetic improvement of industrial pigs.

Keywords: Sows artificial insemination, traditional cervical insemination (CAI), post-cervical artificial insemination (PCAI), meta-analysis, the farrowing rate, fecundity index, the litter size.



МЕТА-АНАЛІЗ МЕТОДІВ ЦЕРВІКАЛЬНОГО ТА ПОСТЦЕРВІКАЛЬНОГО ОСІМЕНІННЯ СВИНОМАТОК

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Ефективність штучного осіменіння (ШО) у свинарстві відіграє вирішальну роль у покращенні репродуктивної продуктивності, зниженні витрат на племінну діяльність та підвищенні стійкості свинарської галузі. На відміну від цервікального осіменіння (САІ), РСАІ дозволяє точніше осідати сперму в матці, підвищуючи шанси на зачаття, а це забезпечує більш ефективне інтенсивне утримання кнурів.

Щоб оцінити ефективність РСАІ у покращенні ефективності розведення свиней, було проведено мета-аналіз з використанням програмного забезпечення Jatovi та алгоритмів із пакету метафор (R). Оцінка похибки публікації була інтегрована в аналіз, щоб забезпечити надійність результатів. Метааналіз порівнював РСАІ та САІ за трьома критичними репродуктивними параметрами: частотою опоросів, індексом плодючості та розміром посліду. Критерії включення дослідження були визначені для забезпечення цілісності аналізу: виключення досліджень, що включають екзогенне гормональне лікування, яке може заважати природним репродуктивним процесам, включення досліджень із принаймні 20 тваринами на групу, наявність розмірів груп і доз осіменіння, і надання відповідної статистики варіації.

Загалом 34 дослідження були включені в аналіз частоти опоросів, 33 дослідження індексу плодючості та 33 дослідження розміру приплоду. Включення такої великої кількості досліджень підвищило надійність мета-аналізу та дозволило провести комплексну оцінку впливу РСАІ на ефективність розведення свиней.

Результати мета-аналізу показали, що РСАІ істотно не погіршує частоту опоросів. Зокрема, середнє логарифмічне співвідношення шансів на основі моделі випадкових ефектів становило 0,0061 (95% ДІ: від -0,2042 до 0,2163), що вказує на відсутність шкідливого впливу на частоту опоросів при застосуванні РСАІ. Подібним чином не було виявлено істотних відмінностей між РСАІ та САІ для індексу плодючості (середня стандартизована середня різниця становила 0,1156; 95% ДІ: від -0,0790 до 0,3103), а також для розміру посліду (середня стандартизована середня різниця становила 0,0226; 95% ДІ: від -0,0670 до 0,1123). Ці результати свідчать про те, що РСАІ можна порівняти з традиційними методами штучного інтелекту з точки зору ключових репродуктивних параметрів, що є вирішальним фактором для селекціонерів, які прагнуть підвищити ефективність виробництва.

Дослідження показали, що використання РСАІ може принести кілька економічних переваг. Підвищуючи ефективність кнурів і роблячи бажану генетику більш доступною, РСАІ зменшує потребу утримувати велику кількість кнурів на фермах. Це не тільки знижує витрати, пов'язані з утриманням кнурів, але й сприяє більш широкому використанню високоякісного генетичного матеріалу, що призводить до генетичного вдосконалення промислових свиней.

Ключові слова: штучне осіменіння свиноматок, традиційне цервікальне осіменіння (САІ), постцервікальне штучне осіменіння (РСАІ), мета-аналіз, частота опоросів, індекс плодючості, розмір гнізда.



Artificial insemination (AI) has been a widely-used practice in pig breeding since the 1930s, but it wasn't until the 1980s that it saw significant commercial use in the industry. Artificial insemination has been an important part of pig breeding for decades, with traditional cervical insemination (CAI) being the most common method used in commercial settings. However, post-cervical AI (PCAI) has been proposed as an alternative method that can reduce insemination time, decrease the number of sperm required per dose, and improve time management for pig farms. The insemination procedure typically involves depositing a dose of semen into the ca of the cervical canal using cervical insemination (CAI), with 2.5-4.0 billion spermatozoa being used per insemination in an extender (70-100 ml). A non-surgical technique for depositing semen into the uterus was proposed by Hancock in 1959 (Hancock, J., & Hovell, G., 1961). This technique, known as post-cervical AI (PCAI), reduces insemination time, allows for a reduction in total sperm number per dose (and it allows for reducing the loss of sperm by backflow (Bortolozzo, F., et al., 2015).), and improves time management for pig farms, resulting in significant productivity gains. By reducing the number of spermatozoa required per dose, PCAI saves on some consumables for artificial insemination and reduces the cost of keeping boars while making desirable genetics more affordable, making it an efficient and effective tool for improving pig breeding efficiency.

The technology of post-cervical insemination, in comparison with traditional cervical insemination, has some specific features, which are related to inner catheter insertion. The cervix must be relaxed for the successful insertion of the internal catheter. Therefore, having the boar present during the process is not recommended. After inserting the basic catheter, it is necessary to wait for 1-3 minutes to allow the cervix to relax before inserting the internal catheter. Typically, insemination is performed for a group of sows at the same time, so while waiting for the cervix to relax, the basic catheters can be inserted for the next sows. It is recommended to allow sows to have contact with the boar after insemination, as this can stimulate uterine motility and improve the transport of sperm to the upper third of the oviduct, where fertilization takes place.

However, the different studies presented controversial results of this method, and the different methodological aspects of research hindered independent analysis. A meta-analysis is a tool capable of creating a comprehensive assessment of results through the data integration of different publications.

In view of this, the aim of the study was to analyze the effects of the post-cervical insemination method in terms of more effective use of boar semen using reproduction parameters (farrowing rate, litter size, and fecundity index of sows).

Materials and methods. The purpose of the meta-analysis was to compare the effectiveness of sows' cervical and post-cervical artificial insemination (by using three reproduction parameters: farrowing rate, fecundity index, and the litter size). The meta-analysis was conducted using Jamovi software and algorithms of the metaphor package (R) algorithms, with publication bias estimation (The Jamovi project, 2022; R Core Team, 2021; Viechtbauer, W., 2010; Francis, G., 2013). The articles selected to create the database were. The following criteria were used for the inclusion of publications in the meta-analysis:

- The study should not involve exogenous hormonal effects on the reproductive system
- The study must have at least 20 animals in each group;
- Information regarding the size of the control and experimental groups, the volume of insemination doses, the total sperm count in one dose, and variation statistics should be available, which are essential for meta-analysis.

We conducted a search of relevant keywords: ("sows" OR "swine" OR "pig") AND ("cervical" OR "post-cervical" AND "artificial insemination» on online databases,



including PubMed and Google Scholar. We then examined the sources cited in the received articles and used them in our study if they were available in full-text versions and contained non-redundant data. In cases where a study included data from multiple experiments, each experiment was considered separately (Table 1). The random effect model was used.

Table 1

Characteristics of included studies

Author, year(n CAI, n PSAI)	Group CAI		Group PSAI	
	Sperm cells in insemination dose, bn	Volume of insemination dose, ml	Sperm cells in insemination dose, bn	Volume of insemination dose, ml
Will K. J., 2021, (158, 90)	1.5	50	1.5	50
Will K. J., 2021, (159, 97)	2.5	80	2.5	80
Singh M., 2020, (40, 30)	1.5	80	1.5	80
Singh M., 2020, (40, 30)	3	80	3	80
Apić J., 2015, (30, 30)	2	50	2	50
Apić J., 2015, (30, 30)	4	50	4	50
Apić J., 2015, (30, 30)	4	100	4	100
Apić J., 2015, (30, 30)	2	100	2	100
Pylypenko S.V., 2006, (25, 25)	2	100	2	20
Kovalenko V.F., 2005, (25, 25)	2	100	2	20
Ternus E. M., 2017, (273, 279)	2.5	80	1.5	45
Llamas-López P. J., 2019, (130, 1036)	2.5	85	1.5	45
Suárez-Usbeck A., 2019, (324, 248)	3	90	1.5	45
Cane F., 2019, (280, 280)	3	100	1.5	50
Hernández-Caravaca I., 2012, (1716, 1683)	3	80	1	25
Hernández-Caravaca I., 2012, (1716, 1664)	3	80	1.5	40
Hernández-Caravaca I., 2017, (38, 104)	3	80	1.5	40
Hernández-Caravaca I., 2017, (38, 38)	3	80	1.5	40
Hernández-Caravaca I., 2017, (38, 42)	3	80	1.5	40
Hernández-Caravaca I., 2017, (47, 56)	3	80	1.5	40
Hernández-Caravaca I., 2017, (47, 54)	3	80	1.5	40
Hernández-Caravaca I., 2017, (47, 63)	3	80	1.5	40
Mellado M., 2018, (1773, 7078)	3	90	3	90
Sbardella P. E., 2014, (165, 165)	3	90	1.5	45
Pearodwong P., 2020, (88, 124)	3	100	1.5	50
Pearodwong P., 2020, (83, 129)	3	100	1.5	50
Fitzgerald R. F., 2008, (196, 193)	3	100	3	100
Dimitrov S., 2009, (49, 67)	3	100	1.5	50
Dimitrov S., 2009, (51, 33)	3	100	1.5	50
Roberts P.K., 2005, (859, 924)	3	80	1	80
Serret C.G., 2005, (95, 83)	3.5	100	2	50
Serret C.G., 2005, (95, 77)	3.5	100	1	50
Serret C.G., 2005, (95, 79)	3.5	100	0.5	50
Llanes Chalé J. E., 2007, (1074, 1510)	4	100	0.5	50



Farrowing rate. We performed a meta-analysis of the farrowing rate using the log odds ratio as the outcome measure. A random-effects model was utilized to analyze the data. The amount of heterogeneity (i.e., τ^2) was estimated using Hedges' estimator (Hedges, 1985). Along with the τ^2 estimate, we reported the Q-test for heterogeneity (Cochran, 1954) and the I^2 statistic. If any level of heterogeneity was detected (i.e., $\tau^2 > 0$, regardless of the Q-test results), a prediction interval for the true outcomes was calculated. Studies with a Cook's distance larger than the median plus six times the interquartile range of the Cook's distances were considered influential. To check for funnel plot asymmetry, we used the rank correlation test and the regression test with the standard error of the observed outcomes as predictors. In total, we included $k=34$ studies in the analysis, with a total of $n(\text{CAI}) = 9962$ and $n(\text{PSAI}) = 16582$ for the farrowing rate.

Fecundity index. We conducted an analysis of the sow's fecundity index using the standardized mean difference (d Hedges') as the outcome measure. We fitted a random-effects model to the data. In total, we included $k=33$ studies in the analysis, with a total of $n(\text{CAI}) = 8111$ and $n(\text{PSAI}) = 9348$ for the fecundity index.

The litter size. We analyzed the variation in the litter size between the study groups of CAI and PSAI insemination using the standardized mean difference as the outcome measure. We fitted a random-effects model to the data. The number of studies included in the analysis was the same as that described in the previous section.

Results

Farrowing rate. The observed log odds ratios for farrowing after PSAI insemination compared to CAI inseminations ranged from -2.1647 to 1.0561, with the majority of estimates being positive for PSAI (56%). The estimated average log odds ratio based on the random-effects model was 0.0061 (95% CI: -0.2042 to 0.2163) (Fig. 1). Therefore, the average outcome did not significantly differ from zero ($z = 0.0564$, $p = 0.9550$). According to the Q-test, the true outcomes of farrowing rates appeared to be heterogeneous ($Q(33) = 68.7814$, $p = 0.0003$, $\tau^2 = 0.1852$, $I^2 = 76.4080\%$). A 95% prediction interval for the true outcomes was -0.8631 to 0.8752. Hence, although the average outcome was estimated to be positive, it did not significantly differ from zero, and in some studies, the true outcome may be negative. An examination of the studentized residuals revealed that none of the studies had a value larger than ± 3.1804 , indicating no outliers in the context of this model.

According to Cook's distances, two studies (Serret C.G., 2005, (95, 83); Serret C.G., 2007, (95, 79)) could be considered overly influential. A funnel plot for estimating the systematic error associated with publication bias (Fig. 2) revealed a low probability of such error. Neither the rank correlation nor the Egger regression test indicated any funnel plot asymmetry ($p = 0.4437$ and $p = 0.0567$, respectively).

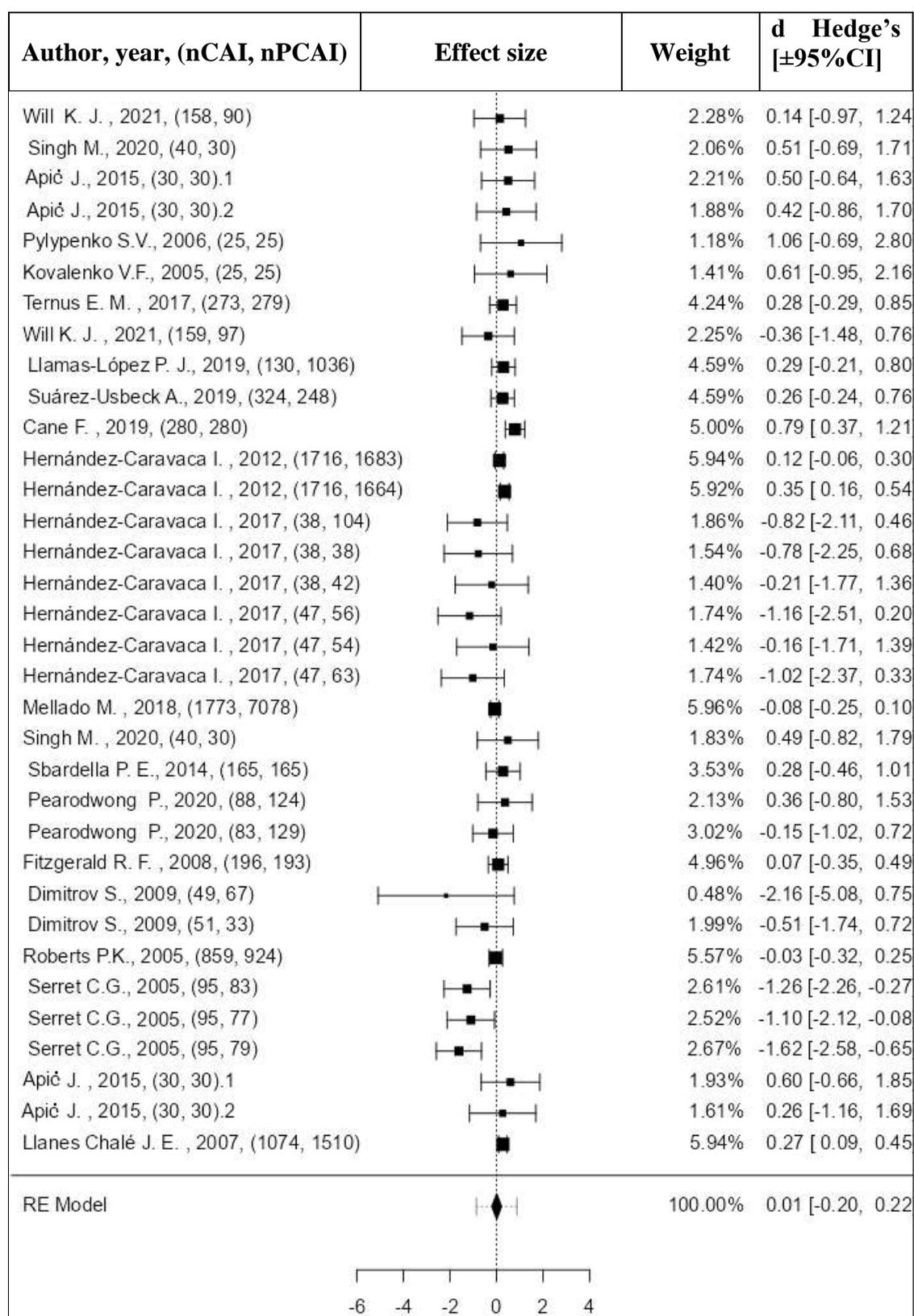


Fig 1. Forest plot showing effects of artificial insemination method of sows on farrowing rate using the log odds ratio as the outcome measure. Figure lists number sows in groups (nCAI and nPCAI), d Hedge's and 95% confidence interval and the weight accounting for the total statistics (weight).

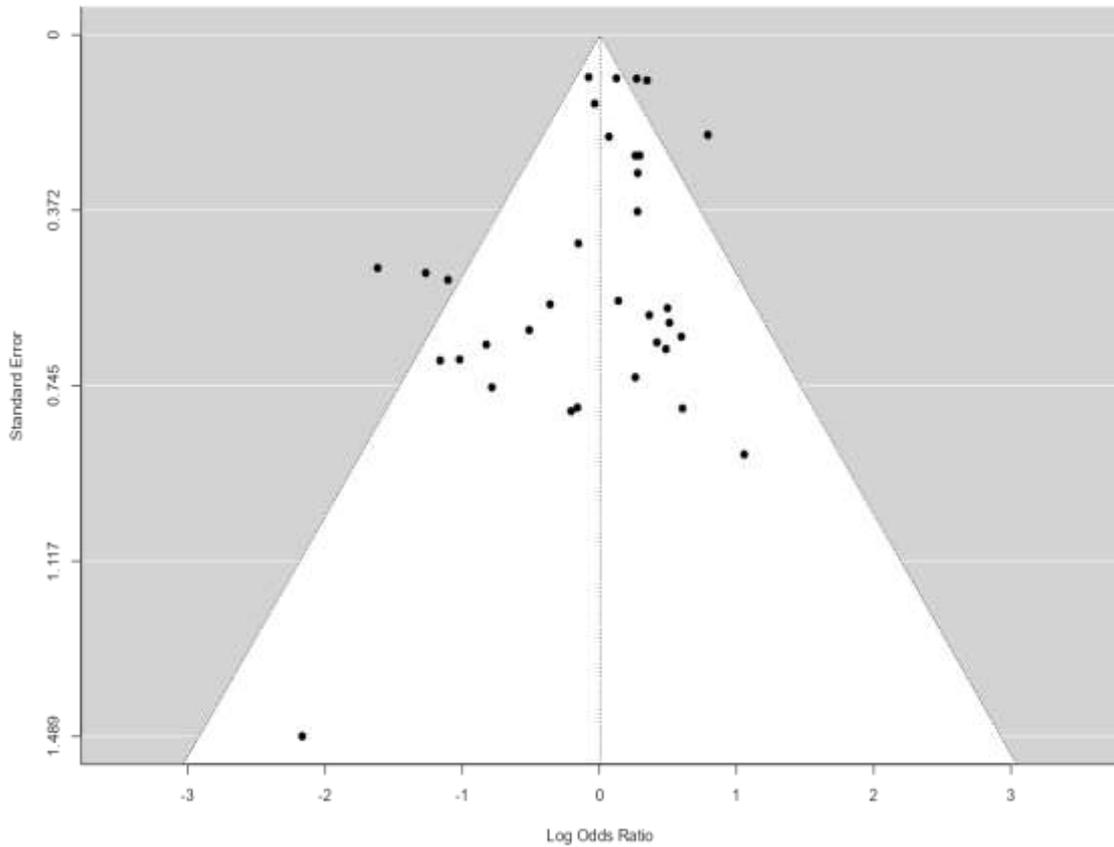


Fig. 2. A funnel plot for estimating the farrowing rate systematic error associated with publication bias. The middle line is the effect size and the side two lines are the corresponding confidence ranges.

Fecundity index. The observed standardized mean differences ranged from -0.7213 to 1.8843, with 52% of the estimates being positive. The estimated average standardized mean difference based on the random-effects model was 0.1156 (95% CI: -0.0790 to 0.3103) (Fig. 3). Therefore, the average outcome did not differ significantly from zero ($z = 1.1642$, $p = 0.2443$). According to the Q-test, the true outcomes appear to be heterogeneous ($Q(32) = 295.6778$, $p < 0.0001$, $\tau^2 = 0.2926$, $I^2 = 97.0358\%$). A 95% prediction interval for the true outcomes is given by -0.9623 to 1.1935. Neither the rank correlation nor Egger's regression test indicated any funnel plot asymmetry ($p = 0.3165$ and $p = 0.0877$, respectively) (Fig. 4).

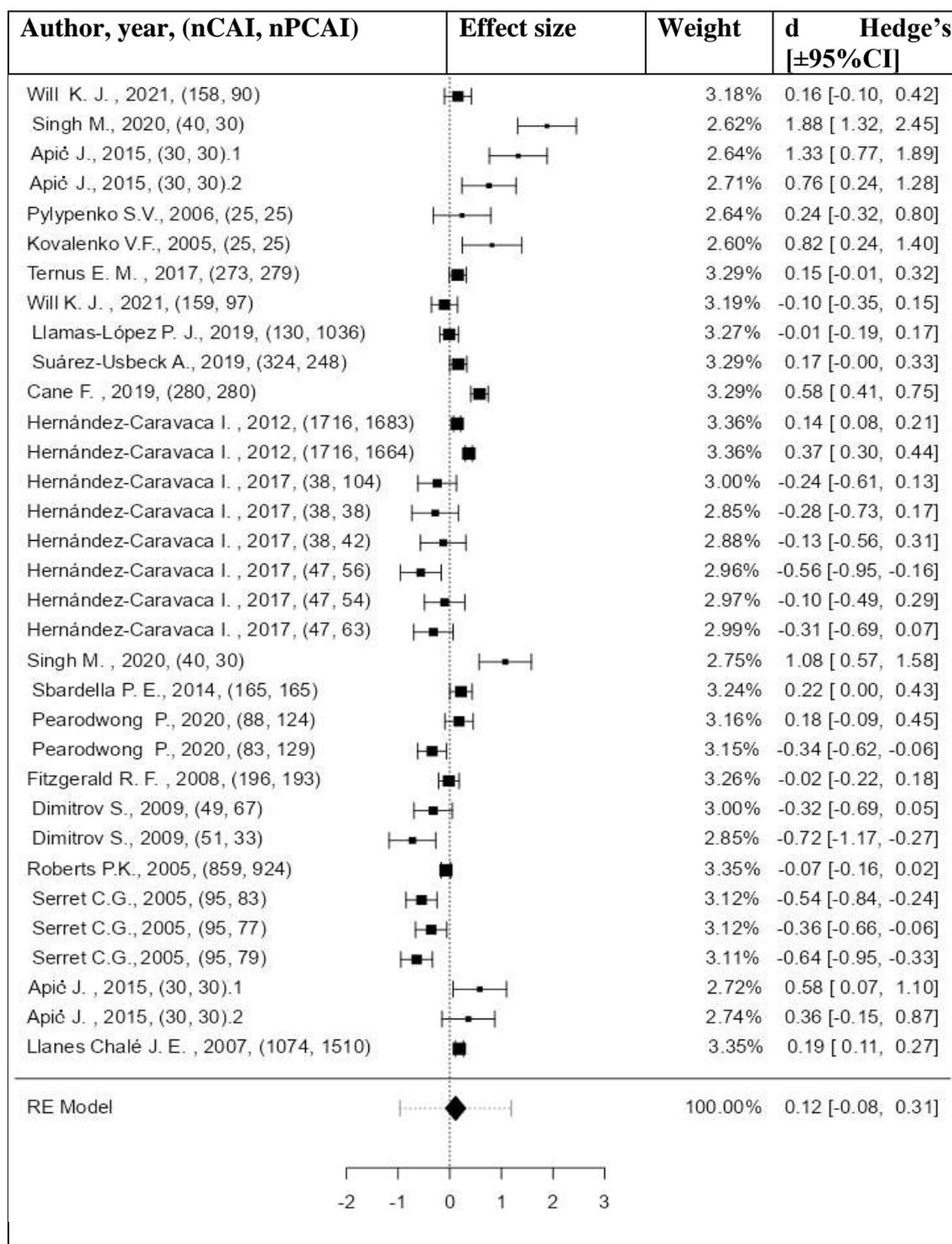


Fig. 3. Forest plot showing effects of artificial insemination method on sow's fecundity index the standardized mean difference as the outcome measure. Figure lists number sows in groups (nCAI and nPCAI), d Hedge's and 95% confidence interval and the weight accounting for the total statistics (weight).

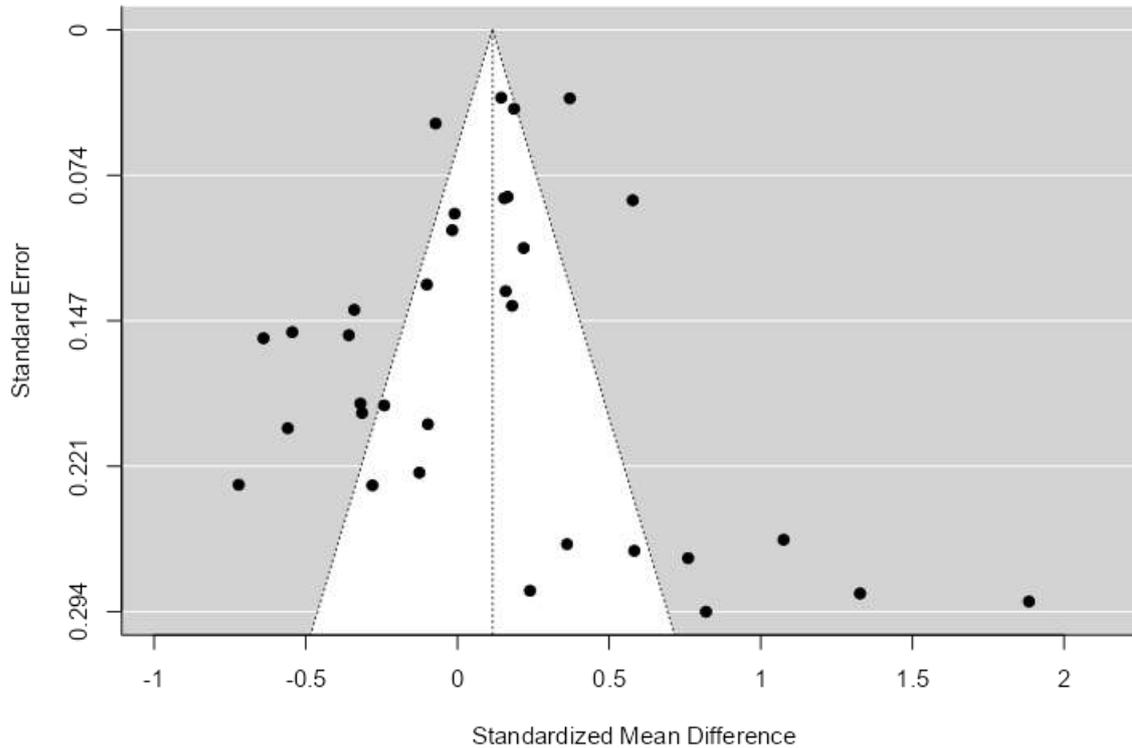


Fig. 4. A funnel plot for estimating the sows' fecundity index systematic error associated with publication bias. The middle line is the effect size and the side two lines are the corresponding confidence ranges.

The litter size. The observed standardized mean differences ranged from -0.4466 to 1.1583, with positive estimates in 52% of cases. The estimated average standardized mean difference, based on the random-effects model, was 0.0226 (95% CI: -0.0670 to 0.1123) (Fig. 5). Therefore, the average outcome did not differ significantly from zero ($z = 0.4950$, $p = 0.6206$). According to the Q-test, the true outcomes appear to be heterogeneous ($Q(32) = 71.9705$, $p < 0.0001$, $\tau^2 = 0.0435$, $I^2 = 83.0904\%$). A 95% prediction interval for the true outcomes is given by -0.3958 to 0.4410. Neither the rank correlation nor Egger's regression test indicated any funnel plot asymmetry ($p = 0.2736$ and $p = 0.3391$, respectively) (Fig. 6).

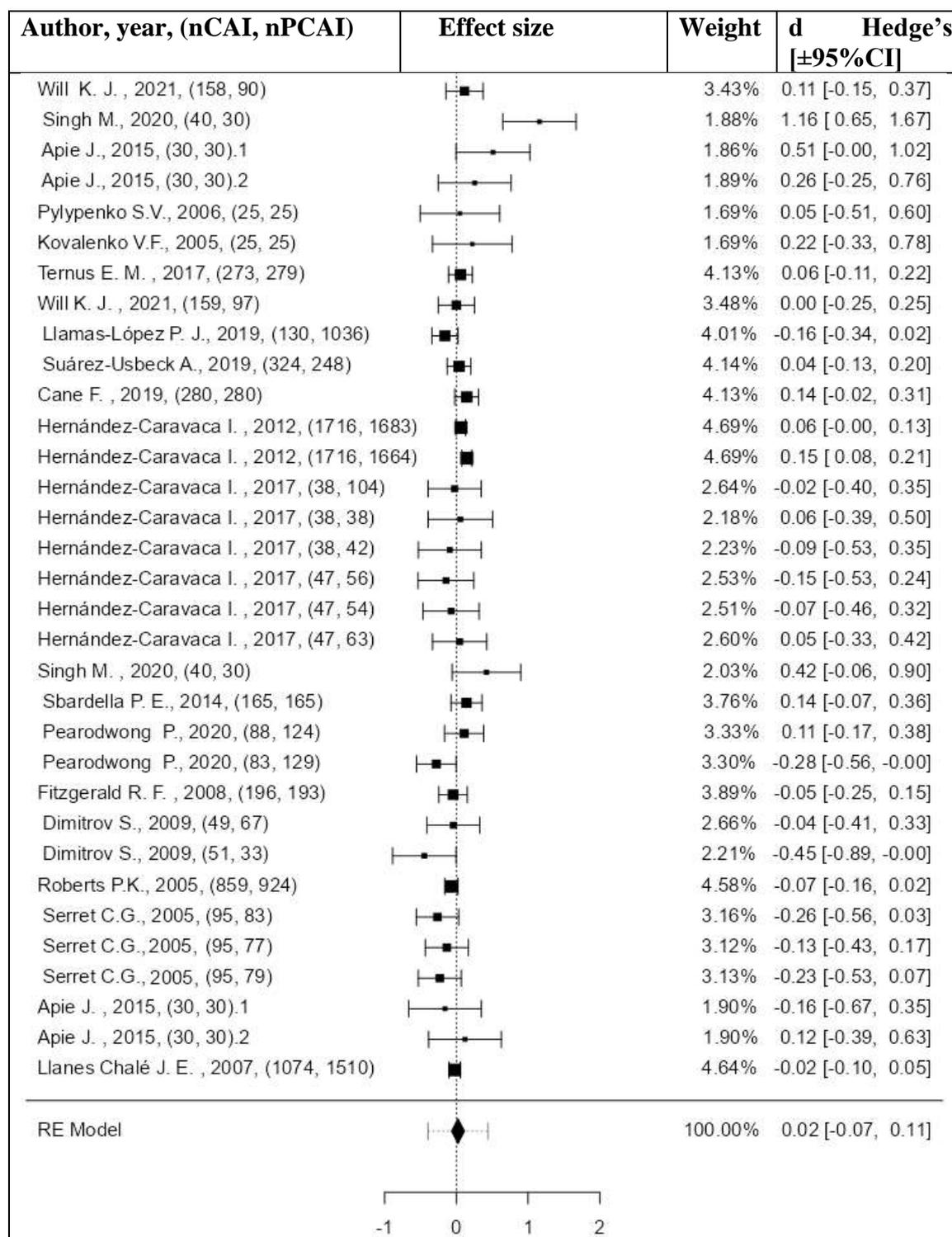


Fig. 5. Forest plot showing effects of sows artificial insemination method on litter size the standardized mean difference as the outcome measure. Figure lists number sows in groups (nCAI and nPCAI), d Hedge's and 95% confidence interval, and the weight accounting for the total statistics (weight).

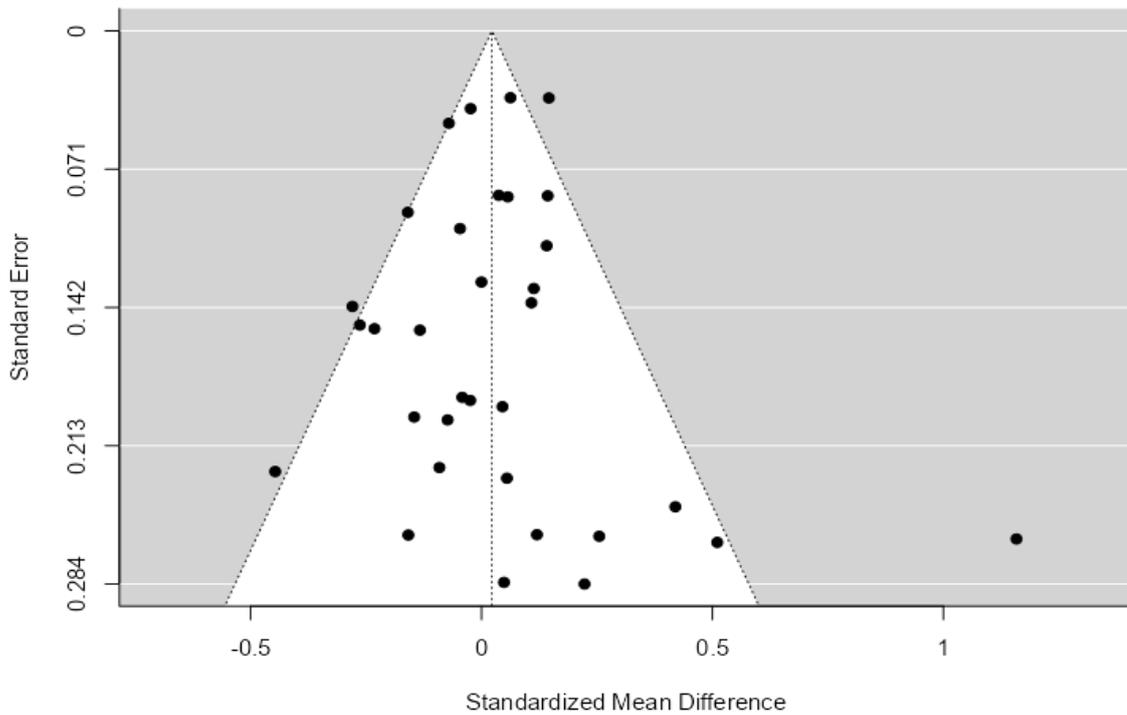


Fig. 6. A funnel plot for estimating the litter size's systematic error associated with publication bias. The middle line is the effect size and the side two lines are the corresponding confidence ranges.

Discussion

The present study demonstrates that none of the investigated parameters (including the farrowing rate, the fecundity index, and the litter size) decreased with the use of the post-cervical insemination method. Therefore, based on the data from various authors analyzed in this meta-analysis, we can conclude that this method offers all the advantages without any loss of reproductive efficiency.

From a methodological standpoint, our dataset was not stratified based on the number of spermatozoa in the semen dose or the volume of the dose when comparing the two methods.

In the analyzed dataset, the number of sperm per dose for traditional insemination ranged from 1.5 billion to 4 billion and the volume of the dose was from 50 to 100 ml. Realistically, industrial doses of less than 70 ml and a total sperm count of less than 2.5 billion are not used. Usually, breeding companies use about 3 billion sperm per dose and a volume of 80-100 ml, this is an effective way to get a good level of fertility in group insemination. So, (Knox R.V., 2016; Roca J., et al., 2006) wrote about 3 billion and 80 ml. The number of sperm per dose for post-cervical insemination ranged from 0.5 billion to 4 billion and the volume of the dose was from 20 to 100 ml. The actual industrial use is about 1.5 billion sperm (Feitsma H., 2009) and the volume of the dose is 35-50 ml.

We separated each group into subgroups where the grouping factor was the number of spermatozoa in the insemination dose. For CAI group, these were concentrations of 1.5-2 million (n=6), 2.5-3 million (n=22), and >3 million (n=6) (Fig. 7, a, b, c). For the PCAI group, these were concentrations of 0.5-1 million (n=5), 1.5-2 million (n=23), and >2 million (n=6) (Fig. 7 (d, e, f). The significance of differences between groups was evaluated by ANOVA (Tables 2, 3).

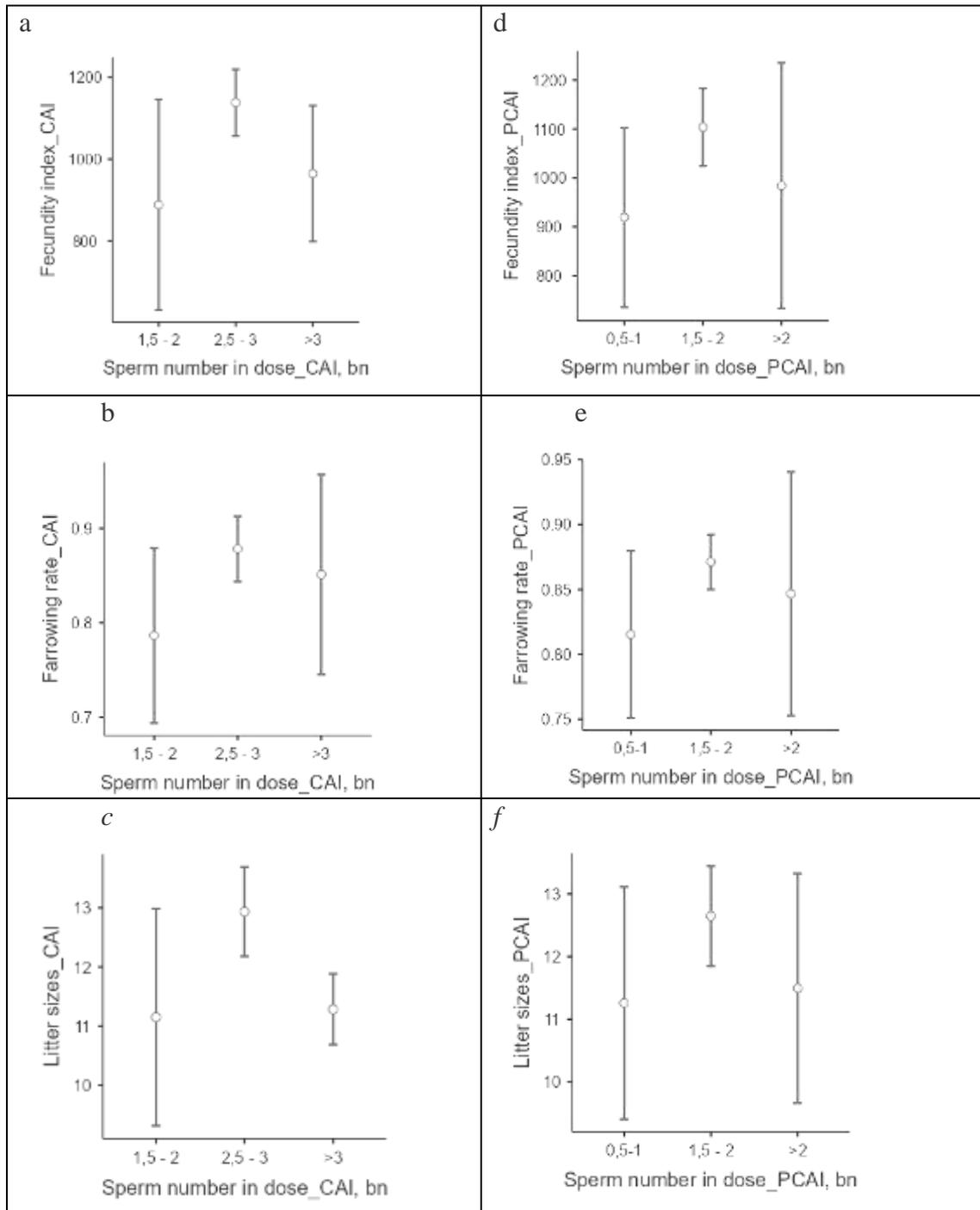


Fig. 7. Fecundity index (a, d), farrowing rate (b, e), and litter sizes (c, f) for CAI and PSAI sow artificial insemination in groups with different total sperm numbers in one dose. Means and 95% CI are shown.

Table 2

One-way ANOVA (Fisher's) result of the effect of sperm numbers per dose on reproductive performance in sows at PCAI

Variables	F	df1	df2	p
Farrowing rate	2.08	2	31	0.142
Fecundity index	2.45	2	31	0.103
Litter sizes	1.87	2	31	0.171



Table 3

One-way ANOVA (Fisher's) result of the effect of sperm numbers per dose on reproductive performance in sows at CAI

Variables	F	df1	df2	p
Farrowing rate	2.84	2	31	0.074
Fecundity index	5.01	2	31	0.013
Litter sizes	4.56	2	31	0.018

In all cases, the absolute values of average groups were optimal. The lowest values were in the case of the smallest sperm counts per dose. However, the differences in fecundity index and litter sizes were significant in the CAE group. Post-cervical insemination offers several benefits in pig breeding, including increased control over semen placement, reduced use of semen material, the potential for increased genetic diversity, and improved herd performance. These advantages make it a popular choice for many farms looking to enhance their breeding programs.

In recent years, there has been a growing interest in the use of post-cervical insemination in the pig industry. The need for more efficient breeding programs has driven the adoption of this technology, as it allows farmers to achieve the same or better results with less effort and resources.

As technology and equipment continue to improve, the use of post-cervical insemination is likely to increase further. It is also expected to play a crucial role in the speed of selective breeding and genetic improvement, making it a valuable tool for the pig industry.

In recent years, there has been a growing interest in the use of post-cervical insemination in the pig industry. Post-cervical insemination offers several benefits in pig breeding, including increased control over semen placement, reduced use of semen material, the potential for increased genetic diversity, and improved herd performance. These advantages make it a popular choice for many farms looking to enhance their breeding programs. The need for more efficient breeding programs has driven the adoption of this technology, as it allows farmers to achieve the same or better results with less effort and resources.

As technology and equipment continue to improve, the use of post-cervical insemination is likely to increase further. It is also expected to play a crucial role in the speed of selective breeding and genetic improvement, making it a valuable tool for the pig industry.

Conclusion. Thus, according to the results of the meta-analysis of the available published data, the method of post-cervical insemination of pigs does not lead to a deterioration of reproductive performance and allows the use of its technological, economic, breeding, and genetic advantages in commercial pig breeding. Also, according to the results obtained, there is no reliable systematic error associated with publication bias.

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