Agro-Science Journal of Tropical Agriculture, Food, Environment and Extension
Volume 23 Number 1 (January 2024) pp. 67 - 73
ISSN 1119-745

CONCEPTION RATE AND LITTER SIZE OF SOWS SUBJECTED TO NATURAL SERVICE VERSUS ARTIFICIAL INSEMINATION IN RWANDA

[1]Makuza J., *[2,3]Bizimana F., [1]Hirwa C.A., [4]Båge R. and [2]Ntawubizi M.

[1]Rwanda Agricultural & Animal Resources Development Board, Huye, Rwanda
[2]School of Veterinary Medicine, University of Rwanda, Nyagatare, Rwanda
[3]Rwanda Institute for Conservation Agriculture, Nyamata, Rwanda
[4]Department of Clinical Sciences, Swedish University of Agricultural Sciences, Uppsala, Sweden

*Corresponding author's email: ferdinandbizimana77@gmail.com

ABSTRACT
This study aimed to characterize the conception rate (CR), litter size, piglet survival rates, of sows subjected to natural service versus artificial insemination (AI) in swine breeding within the Northern Province of Rwanda. Pig farming in Rwanda is mainly small-scale, with few medium-sized operations. A total of 583 sows gilts, representing four breeds namely Landrace (n = 188), Landrace × Pietrain (n = 330), Large White (n = 26), local breed (n = 39) was monitored from March to December 2019 across three agricultural seasons. The sows varied in age from 0.7-4.3 years. Data collected included estrus type (induced, 252; natural, 331), mating type (AI, 266; natural service, 317), number of mating (one service, 359; two services, 164, three services, 60), age, parity, CR, gestation length, litter size, and piglet survival rate. Using descriptive statistics, Chi-square and analysis of variance tests, the study analysed effects of breed, age, farm, season, service type and number on CR, litter size, and weaning rate. Results showed that CR (90.2%) was not affected by sow parity but significantly influenced by boar age and number of services. Mean litter size, born alive were 8.70 ± 3.90, 8.60 ± 3.90 piglets per sow, respectively, with a survival rate of 94%. In conclusion, boar age, mating frequency, farm type, boar and sow breed influence conception rates, litter size, and piglet survival. The study highlights AI potential to improve CR and effectively manage litter sizes.

Key words: AI, East Africa, pig, sow productivity, sow fertility

INTRODUCTION
Artificial insemination (AI) technology allows pig farmers to cut production costs by maintaining fewer breeding boars and enhancing genetic progress by diluting semen doses and shortening the generation interval within swine herds (Parkinson and Morrell, 2019). In large-scale farming, swine AI has mostly replaced natural mating (Ronald *et al.,* 2013). This shift reduces labor costs by increasing the efficiency of boar utilization (Ichikawa and Koketsu, 2011). Recent reports indicate that the global pig population stands at 778 million, with China accounting for 434.22 million of these (Gale *et al.,* 2023). China is also the leading producer of pork, with 57.94 million tons, which represents 50% of global annual pork production and was ranked number 3 in annual pork consumption per capita at 39.90 kg/capita, coming behind the EU and Korea, with 42.70-41.50 kg per capita, respectively (Kim *et al.,* 2024). In sub-Saharan Africa, Malawi leads in per capita pork consumption with 12 kg (FAO, 2020). Consequently, there should be increased efforts to boost pork production and consumption across the continent. Recent reports in Rwanda put the national pig herd at 1,441,000 animals (MINAGRI, 2022) and contribute 12% of the Rwandan GDP, and significantly 32% to the agricultural GDP (National Institute of Statistics of Rwanda, 2017). Pigs are often raised on small plots of land in Rwanda, where feed availability and high lack of quality pig genetics pose significant obstacles for smallholder farmers (Adesehinwa *et al.,* 2024).

Moreover, the AI in pig breeding and other non-bovine livestock is quite limited in Rwanda (FAO, 2023). The primary goal of AI is to spread superior genes throughout a population at an affordable cost (Mbuza *et al.,* 2016). The main benefit of promoting AI is that it enables the extensive use of exceptional breeding sires, facilitating the dissemination of valuable genetics to both large and small-scale farms, which accelerates the genetic improvement of the national pig herd (Gerrits *et al.,* 2005). In northern Rwanda, AI technology has been implemented on private farms, but its community-level application remains untested, as small to medium-scale farmers continue to use boars from neighbouring farms for breeding sows (Niyiragira *et al.,* 2018). Consequently, this practice of communal boars promotes the spread of diseases especially African swine fever (ASF) and various reproductive diseases because of the movement and contact between animals (Bellini *et al.,* 2021). Also, sharing boars among farmers may lead to overuse, potentially causing small litter sizes and fewer

Please cite as: Makuza J., Bizimana F., Hirwa C.A., Båge R. and Ntawubizi M. (2024). Conception rate and litter size of sows subjected to natural service versus artificial insemination in Rwanda. *Agro-Science*, **23 (2)**, 67-73. https://dx.doi.org/10.4314/as.v23i2.9

piglets per sow annually, resulting in economic losses (Niyiragira *et al.*, 2018). Pig AI involves collection of semen from a boar and introduce it into a sow or gilt using a catheter (Broekhuijse *et al.,* 2012). This method differs from natural service, where a boar mounts the sow and deposits semen through copulation (Am-in *et al.*, 2010).

Recent estimates suggest that over 19 million artificial insemination operations are performed on pigs globally each year, with almost all of them (99%) using boar semen stored at temperatures between 15-20°C (Mellagi *et al.,* 2023). In Rwanda, the pig breeds reared include Large White on 22.9% of pig farms, Landrace on 37.7%, and Pietrain on 7.3%. Duroc (1.6%), Local (2.3%), and nondescript crossbred (28.1%) pigs (Mbuza *et al*., 2016). Local pigs are either black or a mix of black and white (Jackline *et al.*, 2023). They have low productivity, with low birth weight, small litter sizes, and slow growth rates. Sows usually have their first farrowing between 18 and 24 months, producing 8-10 piglets per litter, and mature pigs reach 120 kg by 18 months (Nwakpu and Ugwu, 2009; Mbuza *et al*., 2016). In Rwanda, Large White pigs reach an average weight of 70 kg by five months, with first farrowing at 12 months and litter sizes of 10-12 piglets. Landrace pigs reach 100 kg in five months, with an average of 9-10 weaned piglets per litter. Pietrain pigs grow more slowly, have low conception rates, smaller litter sizes, but produce primarily lean carcasses (Niyiragira *et al.*, 2018). During each natural mating, the boar deposits more than 50 $\times 10^9$ spermatozoa in the cervical canal (Baishya and Biswas, 2022). On the other hand, AI can offer more substantial services, being used whenever needed and with relatively important semen dilution, inseminated at only 3-4 $\times 10^9$ sperm by service (Namuncura *et al.,* 2020). Besides those unparallel advantages, AI in pigs remains relatively unknown to farmers in small scale production systems, and policy making still needs evidence of its efficacy and comparative cost effectiveness for its wide promotion (Sharma *et al.,* 2020). Therefore, the present study aimed to investigate the conception rate and litter size of sows subjected to natural service versus artificial insemination in swine breeding across all five districts in the Northern Province of Rwanda.

MATERIAL AND METHODS

Area and Duration of the Study

The study was carried out in the five districts of the Northern Province: Musanze, Gakenke, Rulindo, Burera and Gicumbi. In total, five farms have been selected by convenience to participate in the study, where a total of 583 breeding sows and gilts subjected to AI services have been monitored between March and December 2019, on three agricultural seasons: long rainy-season (March-June), long dry-season (June-August), and short rainy-season (September-December). Details on the study area are highlighted in Figure 1.

Figure 1: Geographical representation of the study area (Northern Province of Rwanda)

Farms and Animals

In this study, pig farms were classified into two categories: four large farms (A, B, C, and D), each with more than 45 sows and gilts, and a fifth category (SHF) consisting of 86 smallholder farms, each with 1-44 sows and gilts. The distribution of these five visited farms across five districts, along with the observed animals, is summarized in Table 1. Animals (sows and gilts) were distributed among 4 breeds; Landrace (n = 188), Landrace × Pietrain (n = 330), Large White (n = 26) and Local breed (n = 39). The observed females were aged between 6.6 months and 4.3 years (1.28 years on average).

Artificial Insemination and Data Collection

On the participating farms, artificial insemination (AI) and natural mating were routine practices, with AI conducted by trained public and private technicians. Farmers, assisted by AI technicians, maintained daily records of reproductive performance. They regularly communicated with the technicians via phone, prompting them to order and transport fresh extended semen from a local private farm as needed. The boars used for both AI and natural mating were categorized into six different breed genotypes: Landrace, Landrace × Pietrain, Large White, Pietrain, Landrace × Local, and Local breeds. Approximately 12 hours after the onset of estrus, a single AI procedure was performed using the intra-cervical (intra-CAI) technique (Kaysen, 2013). Depending on the technician's and farmer's judgment, the procedure could be repeated once or twice at 12-hour intervals if deemed necessary. Pregnancy was confirmed by the absence of a return to estrus after 21 days. The collected data were pertaining to various parameters including estrus type: induced (n = 252), natural (n = 331); mating type: AI service (n = 266), natural service (n = 317); number of mating services: one service (n = 359), two services (n = 164), three services (n = 60); others included age of animals, parity, conception rate, gestation length (days), litter size (number of born alive plus stillborn piglets) and number of weaned piglets per sow (piglet survival rate).

Table 1: Distribution of the five observed farms by districts and the number and proportion of sows and gilts

Farm (station)	Location	Sow and gilts (*n*)	Sow and gilts (%)
A	Gicumbi	88.00	15.00
B	Rulindo	235.00	40.30
C	Rulindo	46.00	7.90
D	Gicumbi	128.00	22.00
Smallholder farms	Musanze, Gakenke and Burera	86.00	14.80
Total		583.00	100.00

Data Analysis and Interpretation

Data were collected and processed using Excel Workbook (Windows descriptive statistics were performed, while fixed effects of boar and sow breed and their age, farm (station), service (type and number) and season on the conception rate, litter size, weaning rate (piglet survival rate) were analysed using one-way ANOVA and Chi-square statistical tests in SPSS Statistics, version 23, with significance determined at $p < 0.05$.

RESULTS

Statistical Description of Various Parameters

Results from 583 observed sows and gilts were statistically described and summarized in Tables 2, 3, 4, and Figures 2, 3, 4, and 5.

Number of services

During the study period most of sows were recorded as having received only one AI or natural service. This category represents 359 (61.6%) of total observations. On the other side, 164 (28.1%) services were recorded as doubled, while only 60 (10.3%) sows received three consecutive services.

Parity

As highlighted in Figure 2, most of the observed sows were gilts at their first mating and primiparous sows.

Gestation length

As indicated in the Figure 3, most of sows (92.2%) were gestating between 114-118 days. It was however indicated that 40 (6.9%) sows did not conceive after AI or natural mating, while eight (1.3%) sows aborted during the study period.

Litter size and weaned piglets (survival rate)

The results on litter size and piglet weaned per sow are presented in Figures 4 and 5. The observed data show notable variation in both parameters across the farms. The litter sizes ranged from a minimum of one piglet per sow to a maximum of 18 piglets per sow, with an average of approximately 8.3 piglets per sow. Similarly, the number of piglets weaned per sow showed high frequencies between 5-13 piglets, with a peak at 10 piglets per sow.

Key factors influencing the conception rate

Table 3 summarizes the findings on the variation in conception rates in sows following insemination or natural service. The results indicate that both the age of the boar and the number of services significantly affected conception rates. However, there was no significant effect of sow age or parity on the likelihood of successful insemination.

Key factors influencing litter size and piglet survival in sows

As shown in Table 4, the results revealed significant variations between farms, with notable effects on litter size ($p < 0.01$) and weaned piglets per sow ($p < 0.01$), while other factors such as breed, estrus type, and season of service also influenced these outcomes to varying degrees.

Table 2: Statistical description for sow and boar age, parity, services, conception rate, liter size and weaned piglets

Parameters	Minimum	Maximum	Sum	Median	Mean	Standard deviation
Age of sow (years)	0.70	4.30		1.20	1.28	0.64
Ageof boar (years)	0.80	4.00		2.00	2.05	0.98
Parity	0.00	8.00		1.00	1.26	1.39
Number of services	1.00	3.00	867.00	1.00	1.49	0.68
Gestation length (days)	0.00	118.00		114.00	106.68	29.03
Number of abortions	2.00	13.00	59.00	6.50	7.38	4.00
Number of stillborn	0.00	6.00	20.00	0.00	1.33	1.84
Born alive	0.00	18.00	5,028.00	9.00	8.62	3.98
Litter size	0.00	18.00	5,048.00	9.00	8.66	3.94
Weaned piglets	0.00	18.00	4,729.00	9.00	8.22	3.71

Table 3: Influence of key factors on the conception rate of sows

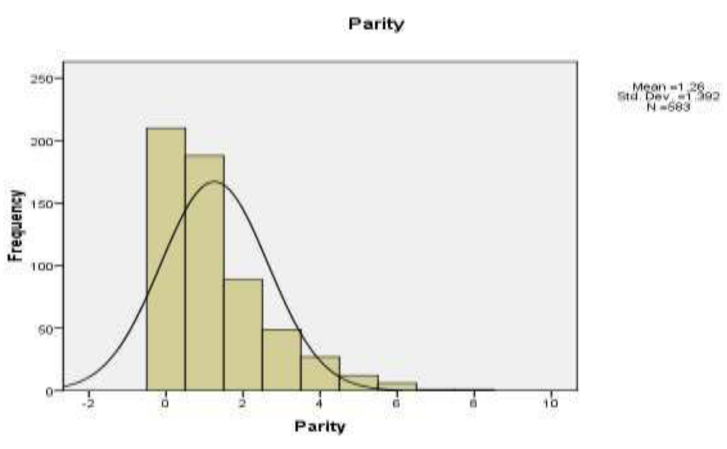
Factors	Conception rate (%)		
	Mean	Standard deviation	*p*-value
Age of sow (year)	1.28	0.63	0.26
Age of boar (year)	2.05	0.98	0.05
Number of parity	1.26	1.39	0.96
Number of services	1.49	0.68	0.03

DISCUSSION

The estimated conception rate was 0.93 ± 0.25, showing considerable variation among sows, which is consistent with findings from Roca *et al.* (2006), where AI resulted in conception rates ranging from 80-90%. Other studies, such as those by Am-in *et al.* (2010), Visalvethaya *et al.* (2011), and Kadirvel *et al.* (2013), have suggested that AI may yield higher farrowing rates and larger litters compared to natural

Table 4: Influence of key factors on the litter size and number of weaned piglets per sow

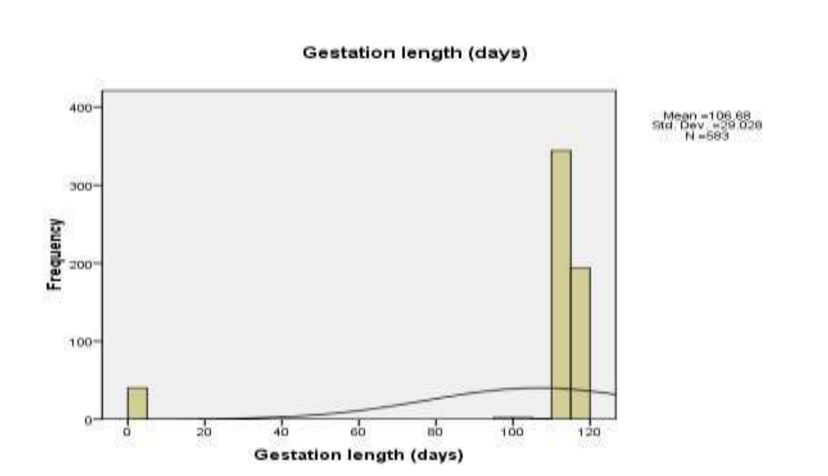
		Litter size		Weaned piglets	
Factors	*n*	Mean ± standard error	*p*-value	Mean ± standard error	*p*-value
Farm (station)			< 0.01		< 0.01
A	88.00	6.70 ± 1.03		6.59 ± 0.96	
B	235.00	8.97 ± 0.89		7.88 ± 0.83	
C	46.00	7.91 ± 0.94		7.40 ± 0.88	
D	128.00	12.98 ± 1.01		12.97 ± 0.94	
Smallholder farms	86.00	7.36 ± 0.93		5.89 ± 0.87	
Sow breed			0.19		0.02
Landrace	188.00	7.91 ± 0.59		6.68 ± 0.55	
Landrace × Pietrain	330.00	8.95 ± 0.53		8.01 ± 0.49	
Large White	26.00	8.60 ± 0.83		8.04 ± 0.77	
Local	39.00	8.18 ± 0.85		7.56 ± 0.79	
Boar breed			0.14		< 0.01
Landrace	192.00	8.98 ± 0.70		8.77 ± 0.65	
Landrace × Local	4.00	10.88 ± 1.72		10.98 ± 1.60	
Landrace × Pietrain	24.00	8.93 ± 0.94		8.86 ± 0.88	
Large White	3.00	6.78 ± 1.93		3.90 ± 1.80	
Local	360.00	8.36 ± 0.67		8.20 ± 0.63	
Estrus type			0.84		0.88
Induced	252.00	8.71 ± 0.87		8.10 ± 0.81	
Natural	331.00	8.86 ± 0.94		8.19 ± 0.87	
Service			0.02		0.03
Artificial insemination	266.00	8.41 ± 0.85		7.80 ± 0.79	
Natural mating	317.00	9.16 ± 0.84		8.49 ± 0.78	
Season			0.54		0.76
Long dry-season	101.00	8.73 ± 0.88		7.99 ± 0.81	
Long rainy-season	268.00	8.65 ± 0.83		8.19 ± 0.78	
Short rainy-season	214.00	8.98 ± 0.84		8.25 ± 0.78	



Parity Distribution		
Parity	Frequency	Percent
0.00	210.00	36.00
1.00	188.00	32.20
2.00	89.00	15.30
3.00	49.00	8.40
4.00	27.00	4.60
5.00	12.00	2.10
6.00	6.00	1.00
7.00	1.00	0.20
8.00	1.00	0.20

Figure 2: Distribution of the observed sows per their parity numbers

mating, aligning with our results. A significant farm effect on piglet survival rate was observed in this study, echoing the findings of Baxter *et al.* (2024), who reported that piglet mortality was significantly influenced by farm management practices. The importance of proper farm management to minimize factors like sow anestrus, abortions, and stillbirths, as discussed by Rutherford *et al.* (2013) and Iida *et al.* (2016) cannot be overstated. Such management practices play a crucial role in optimizing both conception rates and litter sizes. Regarding parity, this study did not find significant effects of sow parity on conception rate, litter size, or piglet survival rate. However, previous research presents differing results. For example, Celestin *et al.* (2019) found higher conception rates and larger litters in sows with more than two parities in Rwanda. Similarly, Klimas *et al.* (2020) observed an increase



Gestation length (days)	Frequency	Percent
0.00	40.00	6.90
96.00	1.00	0.20
98.00	1.00	0.20
100.00	1.00	0.20
101.00	1.00	0.20
106.00	1.00	0.20
114.00	344.00	59.00
115.00	80.00	13.70
116.00	77.00	13.20
117.00	23.00	3.90
118.00	14.00	2.40

The blue color shows the normal gestation length

Figure 3: Distribution of gestation lengths in observed sows

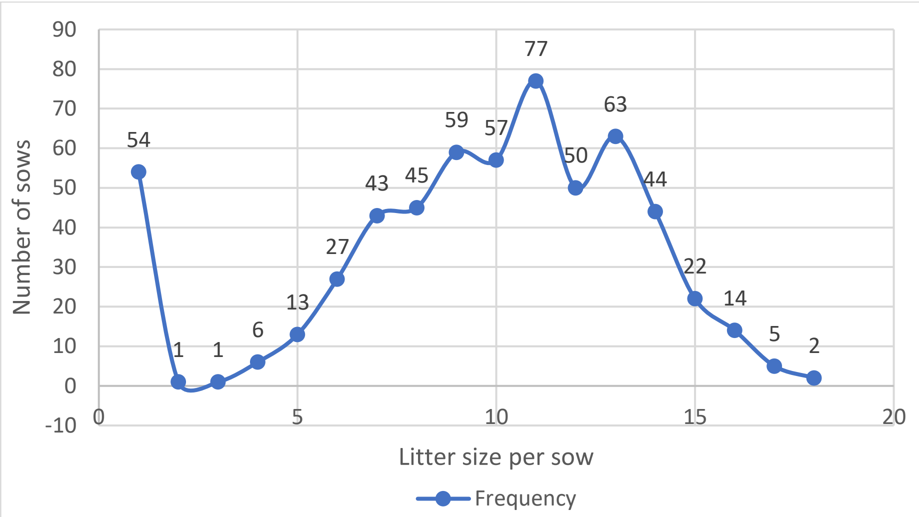
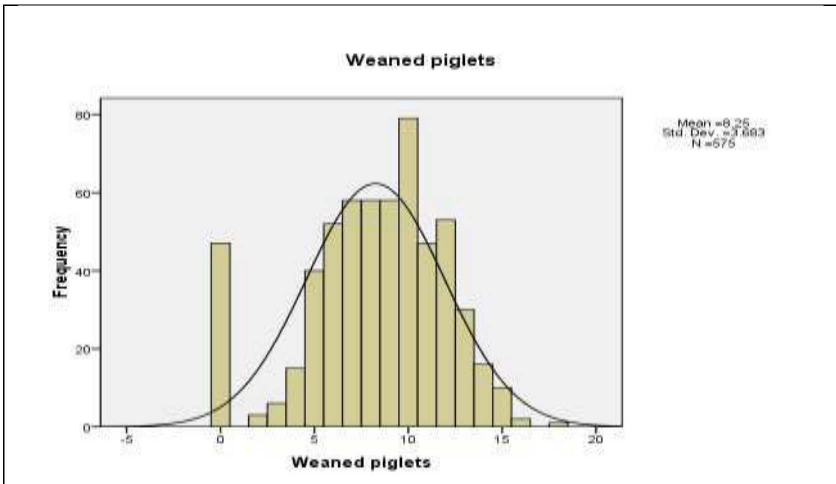


Figure 4: Distribution of litter sizes among sows



Weaned piglets	Frequency	Percent
0.00	47.00	8.10
2.00	3.00	0.50
3.00	6.00	1.00
4.00	15.00	2.60
5.00	40.00	6.90
6.00	52.00	8.90
7.00	58.00	9.90
8.00	58.00	9.90
9.00	58.00	9.90
10.00	79.00	13.60
11.00	47.00	8.10
12.00	53.00	9.10
13.00	30.00	5.10
14.00	16.00	2.70
15.00	10.00	1.70
16.00	2.00	0.30
18.00	1.00	0.20

Survival rate highlighted in blue.

Figure 5: Number of weaned piglets per sow during the study period

in litter size up to parities 5 and 6 in Large White and Landrace sows. Koketsu *et al.* (2017) also reported high conception rates in gilts and young sows, with optimal reproductive performance in sows between parities 2 and 5. Additionally, a study by Koketsu and Dial (1998) noted that younger sows, particularly gilts, might experience lower pregnancy rates due to reduced feed intake during lactation under certain environmental conditions, which could impact reproductive performance. The study also examined the number of services per sow, with 61.58% of the total observations receiving either one AI or natural service, while a smaller portion received double or triple services. Research by Soede *et al.* (1995) and Nissen *et al.* (1997) highlighted the importance of service timing and frequency in influencing pregnancy rates. In regions such as Western Europe and North America, a high percentage of female pigs and gilts are artificially inseminated, with AI generally not showing significant differences in conception rates compared to natural service (Kadirvel *et al.* 2013). However, factors such as awareness, access to AI, and varying farming practices may contribute to differences in results, as noted by Mbuza *et al.* (2016) and Niyiragira *et al.* (2018) in the context of Rwanda. The study found that the maximum recorded litter size was 18 piglets per sow, with an average of 8.7 piglets per sow, demonstrating considerable variability across farms (standard deviation = 3.9). This variation in litter size, along with significant differences in weaned piglets per sow across farms (Table 4), highlights the importance of farm-specific factors in reproductive performance. The piglet survival rate was estimated at 93.7%, suggesting overall good health and management practices. Notably, most sows had gestation periods ranging from 114 to 118 days, although 40 sows failed to show gestation signs after insemination, and 8 sows experienced abortions. This is consistent with reports of Johnson *et al*. (1999) and Hanenberg *et al*. (2001), indicating a normal gestation length of 114 days ± 2 days with litters born before the 112th day considered as abortions.

CONCLUSION

Overall, this study highlights the critical role of farm management, parity, service type, and breed in influencing sow reproductive performance in Rwanda. While AI appears to offer comparable results to natural service, the observed farm effects, as well as the importance of proper management practices, underline areas for improvement to optimize reproductive outcomes in swine breeding.

ACKNOWLEDGMENTS

The author extends heartfelt gratitude to the pig farmers of the Northern Province of Rwanda for their invaluable cooperation and information, which significantly contributed to the success of this study.

Author Contributions

Conceptualization, J.M., F.B., and M.N.; methodology, J.M., F.B., and M.N.; validation, J.M., F.B., and M.N.; formal analysis, M.N., investigation, J.M.; resources, J.M., F.B., and M.N.; data curation, J.M.; project administration, J.M.; writing—original draft preparation, M.N. and F.B.; review and editing, M.N., C.H., and R.B.; supervision, F.B. and M.N. All authors read and agreed to the published version of the manuscript.

Funding

This research was self-funded by the authors.

Conflict of Interest

The authors declare that they have no known competing financial or non-financial, professional, or personal conflicts in the production of this paper.

Data Availability

The datasets generated and analysed during the current study are available and we are currently working on uploading the dataset to a repository once the link provided. The data was curated and managed in Microsoft Excel and analysed using SPSS Statistics for Windows, Version 23.0 (IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp).

REFERENCES

Adesehinwa A.O.K., Boladuro B.A., Dunmade A.S., Idowu A.B., Moreki J.C. and Wachira A.M. (2024). Invited review, pig production in Africa: Current status, challenges, prospects and opportunities. *Anim. Biosci.,* **37 (4),** 730-741. https://doi.org/10.5713/ab.23.0342

Am-in N., Tantasuparuk W. and Techakumphu M. (2010). Comparison of artificial insemination with natural mating on smallholder farms in Thailand, and the effects of boar stimulation and distance of semen delivery on sow reproductive performance. *Trop. Anim. Health Prod.,* **42 (5),** 921-924. https://doi.org/10.1007/s11250-009-9508-3

Baishya S.K. and Biswas R.K. (2022). Recent development in freezing strategies of pig semen-a review. *Ind. J. Anim. Sci.,* **92 (2),** 153-165. https://doi.org/10.56093/ijans.v92i2.122071

Baxter E.M., Bowers N., King R., Brocklehurst S. and Edwards S.A. (2024). Factors contributing to high performance of sows in free farrowing systems. *Porc. Health Manage.,* **10 (1),** 16. https://doi.org/10.1186/s40813-024-00366-w

Bellini S., Casadei G., De Lorenzi G. and Tamba M. (2021). A review of risk factors of African swine fever incursion in pig farming within the European Union scenario. *Pathogens,* **10 (1),** 84. https://doi.org/10.3390/pathogens10010084

Broekhuijse M.L.W.J., Feitsma H. and Gadella B.M. (2012). Artificial insemination in pigs: Predicting male fertility. *Vet. Quart.,* **32 (3-4),** 151-157. https://doi.org/10.1080/01652176.2012.735126

Celestin M., Valentine N., Isaac M. *et al.* (2019). Factors influencing success of artificial insemination of pigs using extended fresh semen in rural smallholder pig farms of Rwanda. *Int. J. Livest. Prod.,* **10,** 101-109. https://doi.org/10.5897/IJLP2018.0562

FAO (2020). World food and agriculture - statistical yearbook 2020. Food and Agriculture Organization of the United Nations, Rome. https://doi.org/10.4060/cb1329en

FAO (2023). Small livestock development in Rwanda: Policy analysis of pig and poultry value chains. Food and Agriculture Organization of the United Nations, Rome. https://doi.org/10.4060/cc7162en

Gale F., Dong F. and United States Department of Agriculture Economic Research Service (2023). China's meat consumption: Growth potential. Economic Research Service, United States Department of Agriculture. https://doi.org/10.32747/2023.8122125.ers

Gerrits R., Joan K., Johnson L., Pursel V., Kraeling R. and Dobrinsky J. (2005). A vision for artificial insemination and genomics to improve the global swine population. *Theriogenol.,* **63,** 283-299. https://doi.org/10.1016/j.theriogenology.2004.09.013

Hanenberg E., Knol E. and Merks J. (2001). Estimates of genetic parameters for reproduction traits at different parities in Dutch Landrace pigs. *Livest. Prod. Sci.,* **69 (2),** 179-186. https://doi.org/10.1016/S0301-6226(00)00258-X

Ichikawa H. and Koketsu Y. (2011). A comparison between artificial Insemination and natural mating for reproductive performance in commercial swine herds. *J. Vet. Epidemiol.,* **15 (2**), 94-99. https://doi.org/10.2743/jve.15.94

Iida R., Piñeiro C. and Koketsu Y. (2016). Abortion occurrence, repeatability and factors associated with abortions in female pigs in commercial herds. *Livest. Sci.,* **185,** 131-135. https://doi.org/10.1016/j.livsci.2016.01.023

Jackline K., Grace K.R. and Gertrude N.K. (2023). Distribution and relative abundance of pig breeds in South-Western Agro-ecological Zone, Uganda: Status of locally adapted pigs. *Int. J. Livest. Prod.,* **14 (1),** 1-12. https://doi.org/10.5897/IJLP2023.0818

Johnson R.K., Nielsen M.K. and Casey D.S. (1999). Responses in ovulation rate, embryonal survival, and litter traits in swine to 14 generations of selection to increase litter size. *J. Anim. Sci.,* **77 (3),** 541. https://doi.org/10.2527/1999.773541x

Kadirvel G., Kumaresan A., Das A., Bujarbaruah K.M., Venkatasubramanian V. and Ngachan S.V. (2013). Artificial insemination of pigs reared under smallholder production system in northeastern India: Success rate, genetic improvement, and monetary benefit. *Trop. Anim. Health Prod.,* **45 (2),** 679-686. https://doi.org/10.1007/s11250-012-0277-z

Kaysen B.L. (2013). *Factors that Impact Probability of Pregnancy when Using AI Boars.* Thesis, Dept. Anim. Sci., Colorado State University, USA, p. 76

Kim S.W., Gormley A., Jang K.B. and Duarte M.E. (2024). Invited review, current status of global pig production: An overview and research trends. *Anim. Biosci.,* **37 (4),** 719-729. https://doi.org/10.5713/ab.23.0367

Klimas R., Klimienė A., Sobotka W., Kozera W. and Matusevičius P. (2020). Effect of parity on reproductive performance sows of different breeds. *South Afr. J. Anim. Sci*., **50 (3),** 434-441. https://doi.org/10.4314/sajas.v50i3.10

Koketsu Y. and Dial G.D. (1998). Interactions between the associations of parity, lactation length, and weaning-to-conception interval with subsequent litter size in swine herds using early weaning. *Prev. Vet. Med.,* **37 (1),** 113-120. https://doi.org/10.1016/S0167-5877(98)00103-2

Koketsu Y., Tani S. and Iida R. (2017). Factors for improving reproductive performance of sows and herd productivity in commercial breeding herds. *Porc. Health Manage.,* **3 (1),** 1. https://doi.org/10.1186/s40813-016-0049-7

Mbuza F., Majyambere D., Ayabagabao J.D. and Dutuze M.F. (2016). Inventory of pig production systems in Rwanda. *Int. J. Livest. Prod.,* **7 (7),** 41-47. https://doi.org/10.5897/IJLP2016.0299

Mellagi A.P.G., Will K.J., Quirino M., Bustamante-Filho I.C., Ulguim R.D.R. and Bortolozzo F.P. (2023). Update on artificial insemination: Semen, techniques, and sow fertility. *Mol. Reprod. Dev.,* **90 (7),** 601-611. https://doi.org/10.1002/mrd.23643

MINAGRI (2022). Ministry of Agriculture and Animal Resources Annual Report, 2021/2022. Retrieved from https://www.minagri.gov.rw/publications/reports

Namuncura C., Sánchez R., Pezo F., Uribe P., Navarro P. and Zambrano F. (2020). Rest days and storage of boar semen at 17°C: Effect on motility and sperm concentration. *Androl.,* **52 (6),** e13578. https://doi.org/10.1111/and.13578

National Institute of Statistics of Rwanda (2017). GDP annual estimates 2017. National Institute of Statistics of Rwanda, Kigali. Retrieved from http://www.statistics.gov.rw

Nissen A., Soede N., Hyttel P., Schmidt M. and D'hoore L. (1997). The influence of time of insemination relative to time of ovulation on farrowing frequency and litter size in sows, as investigated by ultrasonography. *Theriogenol*., **47 (8),** 1571-1582. https://doi.org/10.1016/S0093-691X(97)00162-3

Niyiragira V., Rugira K.D. and Andre H.C.D. (2018). Success drivers of pig artificial insemination based on imported fresh semen. *Int. J. Livest. Prod.,* **9 (6),** 102-107. https://doi.org/10.5897/IJLP2018.0467

Nwakpu P. and Ugwu S. (2009). Heterosis for litter traits in native by exotic inbred pig crosses. *Agro-Science,* **8 (1).** https://doi.org/10.4314/as.v8i1.44111

Parkinson T.J. and Morrell J.M. (2019). Artificial insemination. In: *Veterinary Reproduction and Obstetrics* (pp. 746-777). Elsevier. https://doi.org/10.1016/B978-0-7020-7233-8.00043-4

Roca J., Vazquez J., Gil M., Cuello C., Parrilla I. and Martinez E. (2006). Challenges in Pig Artificial Insemination. *Reprod. Domest. Anim.,* **41,** 43-53. https://doi.org/10.1111/j.1439-0531.2006.00768

Ronald B.S.M., Jawahar T.P., Gnanaraj P.T. and Sivakumar T. (2013). Artificial insemination in swine in an organized farm–a pilot study. *Vet. World,* **6 (9),** 651-654. https://doi.org/10.14202/vetworld.2013.651-654

Rutherford K., Baxter E., D'Eath R. *et al.* (2013). The welfare implications of large litter size in the domestic pig I: Biological factors. *Anim. Welf.,* **22 (2),** 199-218. https://doi.org/10.7120/09627286.22.2.199

Sharma P.R., Singh M., Sinha P.K., Mollier R.T. and Rajkhowa D.J. (2020). Factors for adoption of artificial insemination technology in pig: Evidence from small-scale pig production system. *Trop. Anim. Health Prod.,* **52 (6),** 3545-3553. https://doi.org/10.1007/s11250-020-02391-7

Soede N.M., Wetzels C.C.H., Zondag W., De Koning M.A.I. and Kemp B. (1995). Effects of time of insemination relative to ovulation, as determined by ultrasonography, on fertilization rate and accessory sperm count in sows. *Reprod.,* **104 (1),** 99-106. https://doi.org/10.1530/jrf.0.1040099

Visalvethaya W., Tantasuparuk W. and Techakumphu M. (2011). The development of a model for artificial insemination by backyard pig farmers in Thailand. *Trop. Anim. Health Prod.,* **43,** 787-793. https://doi.org/10.1007/s11250-010-9764-2