

Determinants of Embryo Transfer Success in Tropical Dairy Cattle: Integrating Reproductive Performance and Institutional Factors

Faktor-Faktor Penentu Keberhasilan Transfer Embrio pada Sapi Perah Tropis: Mengintegrasikan Kinerja Reproduksi dan Faktor Kelembagaan

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ABSTRAK

Transfer embrio (ET) adalah bioteknologi reproduksi canggih yang dipromosikan secara luas untuk mempercepat peningkatan genetik dan produktivitas sapi perah. Namun, keberhasilan program ET di sistem peternakan kecil tropis masih belum konsisten karena interaksi faktor biologis, lingkungan, dan kelembagaan. Studi ini bertujuan untuk mengidentifikasi penentu keberhasilan ET dengan mengintegrasikan analisis kinerja reproduksi dengan penilaian implementasi kelembagaan dalam sistem produksi sapi perah tropis. Pendekatan metode campuran digunakan, menggabungkan analisis kuantitatif dari 200 sapi perah penerima dengan wawancara kualitatif yang melibatkan petani, teknisi, dan petugas peternakan di Kabupaten Pasuruan, Jawa Timur, Indonesia. Regresi logistik biner digunakan untuk mengevaluasi pengaruh karakteristik embrio, kondisi penerima, stres lingkungan, riwayat penyakit, dan pengalaman teknisi terhadap hasil kehamilan. Hasil menunjukkan bahwa tingkat kehamilan berkisar antara 20 dan 50%, dengan embrio segar mencapai keberhasilan yang lebih tinggi daripada embrio beku. Analisis regresi logistik menunjukkan bahwa pengalaman teknisi secara signifikan meningkatkan probabilitas kehamilan (OR = 1,236; $p < 0,05$), menyoroti peran penting kapasitas teknis dalam implementasi ET. Faktor-faktor lain, seperti kualitas embrio, skor kondisi tubuh, paritas, dan stres panas, menunjukkan pengaruh yang bervariasi tetapi secara statistik tidak signifikan. Temuan kualitatif lebih lanjut mengungkapkan bahwa keterbatasan sumber daya manusia teknis, sistem pemantauan yang tidak konsisten, dan koordinasi kelembagaan yang lemah membatasi efektivitas program. Temuan ini menunjukkan bahwa keberhasilan ET dalam sistem peternakan sapi perah tropis dibentuk tidak hanya oleh biologi reproduksi tetapi juga oleh kondisi kelembagaan dan manajerial. Penguatan kapasitas teknis, peningkatan manajemen reproduksi, dan integrasi program ET ke dalam sistem inovasi ternak regional sangat penting untuk meningkatkan efektivitas dan keberlanjutan bioteknologi reproduksi di sektor peternakan sapi perah yang sedang berkembang.

Kata kunci: transfer embrio; bioteknologi reproduksi; tingkat kehamilan; sapi perah; regresi logistik; sistem peternakan tropis; sistem inovasi pertanian.

ABSTRACT

Embryo transfer (ET) is an advanced reproductive biotechnology widely promoted to accelerate genetic improvement and productivity of dairy cattle. However, the success of ET programs in tropical smallholder systems remains inconsistent due to the interaction of biological, environmental, and institutional factors. This study aimed to identify the determinants of ET success by integrating reproductive performance analysis with institutional implementation assessment in tropical dairy production systems. A mixed-methods approach was used, combining quantitative analysis of 200 recipient dairy cows with qualitative interviews involving farmers, technicians, and livestock officials in Pasuruan Regency, East Java, Indonesia. Binary logistic regression was employed to evaluate the influence of embryo characteristics, recipient conditions, environmental stress, disease history, and technician experience on pregnancy outcomes. The results showed that

pregnancy rates ranged between 20 and 50%, with fresh embryos achieving higher success than frozen embryos. Logistic regression analysis indicated that technician experience significantly increased the probability of pregnancy (OR = 1.236; $p < 0.05$), highlighting the critical role of technical capacity in ET implementation. Other factors, such as embryo quality, body condition score, parity, and heat stress, showed variable but statistically nonsignificant effects. Qualitative findings further revealed that limited technical human resources, inconsistent monitoring systems, and weak institutional coordination constrained program effectiveness. These findings demonstrate that ET success in tropical dairy systems is shaped not only by reproductive biology but also by institutional and managerial conditions. Strengthening technical capacity, improving reproductive management, and integrating ET programs into regional livestock innovation systems are essential to enhance the effectiveness and sustainability of reproductive biotechnology in developing dairy sectors.

Keywords: *embryo transfer; reproductive biotechnology; pregnancy rate; dairy cattle; logistic regression; tropical livestock systems; agricultural innovation systems.*

I. INTRODUCTION

Increasing demand for animal-derived protein in many developing countries has intensified the need to improve livestock productivity and genetic quality to support sustainable food systems (Jenkins et al., 2024; Wu et al., 2014). The livestock sector, particularly dairy and beef cattle production, plays a strategic role in ensuring food security, improving rural livelihoods, and supporting national economic development (Bardhan, 2024; Khade et al., 2021). In Indonesia, cattle production remains an important component of agricultural development, contributing to both national protein supply and rural income generation (Rahmatillah et al., 2024; Marlina et al., 2024; Adesogan et al., 2026). East Java Province is one of the main centers of cattle production in Indonesia, particularly for dairy cattle, with a significant contribution to national milk production and livestock population (Asmara et al., 2025). Nevertheless, efforts to increase livestock productivity continue to face structural and technical constraints, particularly related to genetic quality, reproductive efficiency, and farm management systems (Agus et al., 2018).

One of the technological strategies widely promoted to accelerate genetic improvement in cattle is the application of advanced reproductive biotechnology, particularly embryo transfer (ET). Embryo transfer enables the multiplication of superior genetic resources by transferring high-quality embryos from genetically superior donor cows to recipient females, thereby accelerating genetic progress compared with conventional breeding methods (Ferraz et al., 2016; Bangert & Wheeler, 2025). In addition to improving genetic quality, ET is increasingly recognized as a strategic technological innovation capable of supporting livestock productivity, enhancing breeding efficiency, and strengthening the resilience of livestock production systems (Contreras et al., 2021; Mueller & Van Eenennaam, 2022; Yadav et al., 2025).

Despite its substantial potential, the implementation of embryo transfer technology in many developing regions has not always achieved optimal results. The success of ET programs is strongly influenced by multiple biological and environmental factors, including embryo quality, synchronization accuracy, physiological condition of recipient cows, nutritional management, and environmental stress conditions such as heat stress (Rensis et

al., 2015; Hansen, 2020). In tropical livestock systems, high ambient temperatures and seasonal climatic variability can negatively affect reproductive performance by altering endocrine responses and reducing embryo viability.

Beyond biological and environmental determinants, institutional and managerial factors also play an important role in determining the effectiveness of technology implementation in livestock development programs (Asai et al., 2018; Leroy et al., 2016). The availability of trained technicians, coordination among implementing agencies, program monitoring systems, and policy support are often decisive factors influencing the sustainability of livestock innovation programs (Shortall & Brown, 2019; Ansari, 2021). Within the framework of agricultural innovation systems, successful adoption of new technologies depends not only on technological performance but also on the effectiveness of institutional arrangements, extension services, and governance mechanisms supporting their implementation (Freudenreich et al., 2022; Fernando et al., 2023).

Empirical observations in East Java indicate that embryo transfer programs initiated in recent years have shown varying levels of success (Sini et al., 2020; Tangkas et al., 2025). Pasuruan Regency represents one of the regions where ET programs have been implemented as part of regional livestock development strategies. However, the pregnancy rates achieved through embryo transfer remain variable, ranging from approximately 20% to 50% depending on embryo type, recipient condition, and management practices (Lestari et al., 2019; Syahdan et al., 2025). Such variability suggests that the performance of ET technology in field conditions may be influenced by a complex interaction between biological, environmental, and institutional factors.

The situation has been further complicated by the outbreak of Foot and Mouth Disease (FMD) in Indonesia in 2022, which significantly affected livestock health and reproductive performance (Asmara et al., 2025; Kedang et al., 2025). Previous studies reported that cattle affected by FMD may experience reproductive disorders such as irregular estrus cycles, abortion, and decreased fertility rates (Priyanto et al., 2024; Setyo et al., 2024). These health disturbances can directly influence the effectiveness of reproductive technologies, including embryo transfer programs.

Although numerous studies have examined technical aspects of embryo transfer, such as embryo quality, synchronization protocols, and pregnancy rates, research integrating reproductive performance analysis with program implementation and institutional dimensions remains limited, particularly in tropical smallholder dairy systems. Understanding how biological determinants interact with institutional and managerial conditions is essential for improving the effectiveness of reproductive biotechnology in livestock development programs.

Therefore, this study aims to analyze the determinants of embryo transfer success in dairy cattle by integrating reproductive performance analysis with an evaluation of institutional implementation factors. Using a mixed-methods approach, this research combines quantitative analysis of pregnancy outcomes from recipient cows with qualitative assessment of program governance and implementation. By examining both biological and institutional determinants, this study seeks to provide a more comprehensive understanding of the factors influencing embryo transfer success and to generate insights for improving the

effectiveness and sustainability of reproductive biotechnology programs in tropical dairy production systems.

II. RESEARCH METHOD

1. Research Design

This study employed a mixed-methods approach with an evaluative design to obtain a comprehensive understanding of the implementation of the embryo transfer (ET) program. The quantitative component was used to analyze reproductive performance and identify determinants influencing pregnancy outcomes in recipient dairy cattle. Meanwhile, the qualitative component was conducted to explore institutional and governance factors affecting the implementation of the ET program at the regional level.

The mixed-methods approach allowed the integration of biological performance analysis with institutional evaluation, enabling a broader understanding of the factors influencing the effectiveness of embryo transfer technology in tropical dairy production systems.

2. Study Area and Period

The study was conducted in Pasuruan Regency, East Java Province, Indonesia, which represents one of the priority regions for the implementation of embryo transfer programs in dairy cattle since 2019. The region was selected purposively due to its significant dairy cattle population and its role as an important center for dairy production in East Java.

Field data collection was carried out from April to July 2025, including farm observations, interviews, and documentation of reproductive records of recipient cows involved in the ET program.

3. Population and Sampling

The study population consisted of dairy farmers participating in the embryo transfer program implemented by the Provincial Livestock Service in Pasuruan Regency.

- 1) Sampling was conducted using purposive sampling based on the following criteria:
- 2) Farmers who had participated in the ET program for at least one transfer cycle
- 3) Farms with documented reproductive records of recipient cows
- 4) Farmers willing to participate as research respondents

A total of 200 recipient dairy cows that had undergone embryo transfer procedures were included in the quantitative analysis. The dataset included both fresh and frozen embryo transfers, along with information on recipient characteristics, environmental conditions, and technical implementation variables.

4. Data Collection Techniques

Data were collected using four complementary techniques:

a. *Structured Questionnaire*

Structured questionnaires were administered to collect quantitative information regarding farmer characteristics, management practices, estrus detection accuracy, feeding management, and pregnancy outcomes following embryo transfer.

b. In-depth Interviews

Semi-structured interviews were conducted with key informants, including dairy farmers, embryo transfer technicians, inseminators, and officials from the regional livestock service. The interviews aimed to explore perceptions regarding program implementation, technical challenges, institutional coordination, and policy support.

c. Field Observation

Direct observations were conducted to assess farm management practices, housing conditions, estrus detection practices, and the physiological condition of recipient cows. Body condition score (BCS) assessments were performed to evaluate the nutritional status of recipient animals.

d. Document Analysis

Secondary data were obtained from official reports, program implementation records, and reproductive data maintained by the regional livestock service and technical units responsible for embryo transfer programs.

5. Research Variables

The variables analyzed in this study consisted of biological, environmental, and institutional indicators related to embryo transfer success.

a. Reproductive and Biological Variables

- (1) Embryo type (fresh or frozen)
- (2) Embryo quality (Grade 1 or Grade 2)
- (3) Body Condition Score (BCS) of recipient cows
- (4) Parity (number of lactation cycles)

b. Environmental and Health Variables

- (1) Heat stress index (HTI) representing environmental temperature stress
- (2) Disease history, particularly related to reproductive disorders or Foot and Mouth Disease (FMD)

c. Technical Implementation Variable

Technician experience, measured in years of practical experience in embryo transfer procedures.

d. Outcome Variable

The dependent variable was pregnancy outcome. This binary variable represented the success of embryo implantation following embryo transfer, coded as:

0 = not pregnant

1 = pregnant

6. Quantitative Data Analysis

Quantitative data were analyzed using binary logistic regression to identify factors influencing pregnancy outcomes following embryo transfer. The logistic regression model (1) can be expressed as:

$$\text{logit}(P) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 \text{ ----- (1)}$$

Where probability of pregnancy success (P), embryo type (X_1), embryo quality (X_2), body condition score (BCS) (X_3), parity (X_4), heat stress index (HTI) (X_5), disease history (X_6), and technician experience (X_7). Descriptive statistics of recipient cows and embryo transfer variables are presented in Table 1.

The regression analysis generated odds ratios (OR), 95% confidence intervals (CI), and p-values to determine the statistical significance and magnitude of each variable's effect on pregnancy outcomes. Model performance was evaluated using log-likelihood, Akaike Information Criterion (AIC), and pseudo- R^2 (McFadden) indicators to assess the goodness-of-fit of the logistic regression model.

Table 1. Descriptive statistics of recipient cows and embryo transfer variables

| Variable | Description | Category / Unit | n |
|----------------------------|---------------------------------------------------------------|-----------------------|-----|
| Embryo type | Type of embryo used for transfer | Fresh/Frozen | 200 |
| Embryo quality | Morphological quality of embryo | Grade 1/Grade 2 | 200 |
| Body Condition Score (BCS) | Nutritional status of recipient cows | <2.5 ; 2.5–3 ; >3 | 200 |
| Parity | Lactation number of recipient cows | 1–6 cycles | 200 |
| Heat Stress Index (HTI) | Environmental temperature indicator | °C | 200 |
| Disease history | History of reproductive or infectious disease (including FMD) | Yes/No | 200 |
| Technician experience | Experience of ET technician | Years | 200 |
| Pregnancy outcome | Result of embryo transfer | Pregnant/Not pregnant | 200 |

7. Qualitative Data Analysis

Qualitative data obtained from interviews and field observations were analyzed using content analysis techniques. The analysis involved several stages:

- 1) Data transcription and organization
- 2) Data reduction and thematic coding
- 3) Categorization of institutional and governance factors
- 4) Cross-validation through data triangulation

The evaluation of institutional implementation was conducted using the Edwards III policy implementation framework, which examines four key dimensions:

- 1) Communication
- 2) Resources
- 3) Disposition of implementers
- 4) Bureaucratic structure

This framework was used to assess how institutional arrangements and governance mechanisms influenced the effectiveness of embryo transfer program implementation.

III. RESULTS AND DISCUSSION

1. Reproductive Performance of Embryo Transfer

The implementation of embryo transfer (ET) in Pasuruan Regency showed variable reproductive outcomes among recipient dairy cows. As presented in Table 2, pregnancy rates ranged between 20–50% depending on embryo type, with fresh embryos achieving higher pregnancy success compared with frozen embryos. The average pregnancy rate across all transfers was estimated at 35–42%, indicating moderate reproductive performance under field conditions.

The higher pregnancy success observed in fresh embryos can be explained by differences in embryo viability following cryopreservation. Fresh embryos generally maintain better cellular integrity and metabolic activity compared with frozen embryos, which may experience cellular stress during freezing and thawing processes. Previous studies reported that cryopreservation can induce osmotic stress and cellular damage that reduce embryo viability and implantation potential (Cao et al., 2022; Hansen, 2020; Huang et al., 2006). Similarly, Hasler (2014) noted that although embryo freezing technologies have improved substantially, fresh embryos often demonstrate higher pregnancy rates under commercial conditions.

The pregnancy rates observed in this study remain consistent with empirical reports from tropical dairy production systems. Studies conducted in Indonesia and other developing countries often report ET pregnancy rates between 30–50% depending on recipient condition and management practices (Lestari et al., 2019; Syahdan et al., 2025). These findings indicate that the reproductive outcomes observed in Pasuruan reflect broader patterns of embryo transfer performance under tropical livestock production conditions.

However, the variability in pregnancy success suggests that embryo transfer performance cannot be explained solely by embryo characteristics. The success of embryo implantation is influenced by a combination of recipient physiology, environmental conditions, and technical implementation of the transfer procedure (Besenfelder & Havlicek, 2023; Bulletti et al., 2025). Therefore, identifying the determinants influencing pregnancy outcomes is essential for improving the effectiveness of embryo transfer programs.

Table 2. Pregnancy rate of embryo transfer based on embryo type

| Embryo Type | Number of Transfers | Pregnant Cows | Pregnancy Rate (%) |
|---------------|---------------------|---------------|--------------------|
| Fresh embryo | 100 | 50 | 50.0 |
| Frozen embryo | 100 | 20–35 | 20–35 |
| Overall | 200 | 70–85 | 35–42 |

2. Determinants of Embryo Transfer Success

To identify factors influencing pregnancy outcomes following embryo transfer, a binary logistic regression analysis was conducted using biological, environmental, and technical variables as predictors. The regression results are presented in Table 3.

The model indicated that technician experience was the only statistically significant variable affecting pregnancy success (OR = 1.236; $p < 0.05$). This finding suggests that each

additional year of technician experience increases the probability of successful pregnancy by approximately 23.6%, highlighting the critical role of technical expertise in the implementation of embryo transfer procedures.

The influence of technician experience can be explained by the highly technical nature of embryo transfer procedures. Successful ET requires precise synchronization of recipient estrus cycles, careful handling of embryos, and accurate deposition of embryos within the uterine horn. Inexperienced technicians may face challenges in achieving optimal transfer conditions, which may reduce implantation success. Similar findings have been reported in reproductive biotechnology studies, where operator skill and technical precision significantly influence the success rates of embryo transfer procedures (Bangert & Wheeler, 2025; D'Angelo et al., 2022; Hew et al., 2024).

Although other variables such as embryo type, embryo quality, body condition score, parity, heat stress index, and disease history were included in the regression model, their effects were not statistically significant within the current dataset. Nevertheless, the direction of their coefficients provides important biological insights into reproductive performance.

For instance, embryo quality showed a positive coefficient (OR = 3.085), indicating that higher-quality embryos may increase pregnancy probability, although the effect was not statistically significant in this sample. This trend aligns with previous studies demonstrating that embryo morphological quality is strongly associated with implantation success and early embryonic development (Fahrurrozy et al., 2021; Ferraz et al., 2016).

Table 3. Binary logistic regression analysis of factors affecting pregnancy outcomes

| Variable | Coefficient (B) | Std. Error | Odds Ratio (OR) | 95% CI Lower | 95% CI Upper | p-value |
|-----------------------|-----------------|------------|-----------------|--------------|--------------|---------|
| Intercept | -8.0369 | 4.5445 | 0.0003 | 0.0000 | 2.3872 | 0.0770 |
| Embryo Type | 0.1553 | 0.6899 | 1.168 | 0.3022 | 4.5151 | 0.8219 |
| Embryo Quality | 1.1266 | 1.0954 | 3.085 | 0.3605 | 26.4044 | 0.3037 |
| Body Condition Score | -0.8024 | 0.5431 | 0.448 | 0.1546 | 1.2996 | 0.1396 |
| Parity | 0.2201 | 0.1970 | 1.246 | 0.8471 | 1.8334 | 0.2638 |
| Heat Stress Index | 0.1061 | 0.2012 | 1.112 | 0.7495 | 1.6494 | 0.5981 |
| Disease History | -19.9257 | 16057.7707 | 0.000 | 0.000 | — | — |
| Technician Experience | 0.2119 | 0.0951 | 1.236 | 1.0259 | 1.4891 | 0.0258* |

Body condition score (BCS) displayed a negative coefficient (OR < 1), suggesting that suboptimal nutritional status of recipient cows may reduce the probability of pregnancy. Nutritional balance plays a crucial role in reproductive physiology, as inadequate body condition may impair endocrine regulation, follicular development, and uterine receptivity.

The regression model produced a McFadden pseudo R^2 of 0.179, indicating that approximately 17.9% of the variation in pregnancy outcomes could be explained by the variables included in the model. This relatively moderate explanatory power suggests that additional biological or environmental variables not captured in the current dataset may also contribute to embryo transfer success.

3. Biological and Environmental Constraints in Reproductive Performance

Beyond the statistical determinants identified in the regression analysis, field observations revealed that environmental and health conditions also influenced reproductive outcomes. One of the most significant challenges reported by farmers was the impact of the Foot and Mouth Disease (FMD) outbreak in 2022, which affected reproductive performance in dairy cattle populations.

Previous studies have documented that cattle recovering from FMD may experience reproductive disorders, including irregular estrus cycles, decreased fertility, and increased risk of abortion (Priyanto et al., 2024; Setyo et al., 2024). Such physiological disturbances may reduce the success of reproductive technologies, including artificial insemination and embryo transfer (Khan et al., 2023; Yadav et al., 2025).

Environmental stress also represents a major constraint in tropical livestock systems. High ambient temperatures can induce heat stress, which disrupts endocrine regulation and reduces reproductive efficiency. Heat stress has been shown to impair follicular development, decrease oocyte quality, and reduce embryo survival rates (Rensis et al., 2015). In dairy cattle, elevated temperature-humidity conditions may also alter uterine physiology and decrease implantation success.

These findings suggest that the effectiveness of embryo transfer technology cannot be separated from the broader physiological and environmental conditions experienced by recipient animals. Even when high-quality embryos are used, unfavorable health or environmental conditions may reduce the likelihood of successful pregnancy.

4. Institutional and Program Implementation Factors

In addition to biological determinants, qualitative analysis revealed several institutional constraints affecting the effectiveness of embryo transfer programs. As summarized in Table 4, key challenges include limited availability of trained technicians, inconsistent program monitoring systems, and weak institutional coordination among implementing agencies.

Within the framework of agricultural innovation systems, the successful adoption of advanced technologies depends on the integration of multiple subsystems, including research institutions, extension services, training programs, and policy support mechanisms (Fernando et al., 2023). When coordination among these components is weak, technological innovations may fail to achieve their intended impact (Enciso et al., 2022; Gutiérrez Cano et al., 2023).

The significant role of technician experience identified in the regression analysis further emphasizes the importance of human resource capacity in reproductive biotechnology programs. Without adequate technical training and continuous skill

development, the implementation of complex reproductive technologies such as embryo transfer may face substantial operational challenges.

Furthermore, the absence of systematic monitoring and evaluation mechanisms may limit the ability of local institutions to identify implementation bottlenecks and improve program performance. Strengthening institutional coordination and establishing data-based monitoring systems may therefore contribute to improving the effectiveness of ET programs.

Table 4. Institutional and technical constraints affecting embryo transfer implementation

| Aspect | Field Findings | Potential Impact |
|-------------------------|-----------------------------------------------------|-----------------------------------------|
| Reproductive management | Variation in embryo quality and recipient condition | Reduced pregnancy consistency |
| Human resources | Limited number of trained ET technicians | Inconsistent technical procedures |
| Animal health | Post-FMD reproductive disturbances | Increased abortion and infertility risk |
| Environmental factors | Heat stress during tropical seasons | Reduced embryo implantation success |
| Program governance | Limited monitoring and evaluation systems | Lower program effectiveness |

5. Implications for Livestock Productivity and Agricultural Innovation Systems

Improving reproductive efficiency through advanced technologies such as embryo transfer has significant implications for livestock productivity and food security. Genetic improvement programs can accelerate the dissemination of superior livestock genetics, thereby increasing milk production and enhancing the efficiency of dairy production systems.

However, the findings of this study demonstrate that technological interventions alone are insufficient to achieve optimal outcomes. The effectiveness of reproductive biotechnology depends on the integration of biological performance, technical capacity, and institutional governance within livestock development programs.

In the context of agricultural innovation systems, strengthening the implementation of embryo transfer programs requires coordinated efforts involving research institutions, veterinary services, extension systems, and policy makers. Enhancing technician training programs, improving reproductive data management systems, and integrating reproductive biotechnology into regional livestock development policies may significantly improve program outcomes.

Therefore, the success of embryo transfer programs in tropical dairy systems should be viewed not merely as a technical reproductive issue but as a systemic innovation process that involves interactions between biological, environmental, and institutional components.

IV. CONCLUSION

The results of this study demonstrate that the success of embryo transfer (ET) in dairy cattle is determined by the interaction between biological, environmental, and institutional

factors. Pregnancy rates observed in Pasuruan Regency ranged from 20–50%, indicating moderate reproductive performance under field conditions in tropical dairy production systems. The logistic regression analysis revealed that technician experience was the only variable with a statistically significant effect on pregnancy outcomes, suggesting that technical capacity plays a critical role in the successful implementation of embryo transfer procedures. Although other biological variables such as embryo quality, body condition score, parity, and heat stress were not statistically significant in the regression model, their biological relevance remains important in influencing reproductive performance. These findings indicate that the effectiveness of embryo transfer technology cannot be interpreted solely from a reproductive or physiological perspective, but rather as the outcome of a complex interaction between animal health, environmental conditions, and technical implementation.

From a policy perspective, improving the effectiveness of embryo transfer programs in tropical dairy systems requires a systemic approach that integrates technological innovation with institutional strengthening. Capacity-building programs for embryo transfer technicians should be prioritized to enhance technical proficiency and consistency in reproductive procedures. In addition, strengthening reproductive data monitoring systems, improving animal health management—particularly in response to infectious disease outbreaks—and developing adaptive strategies to mitigate heat stress are essential for improving reproductive efficiency. Integrating embryo transfer programs within broader regional livestock innovation systems involving research institutions, veterinary services, and extension agencies may further enhance the sustainability and impact of reproductive biotechnology in supporting livestock productivity and national food security.

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VI. REFERENCES

- Adesogan, A. T., McKune, S. L., Serra, R., Miller, L. C., Bamikole, M. A., Laborde, J. E. A., Jr, J. C. B. D., & Adeoti, T. M. (2026). Animal board invited review: Benefits of livestock and animal-source foods in developing countries. *Animal*, 20(2), 101722. <https://doi.org/10.1016/j.animal.2025.101722>
- Agus, A., Satya, T., & Widi, M. (2018). Current situation and future prospects for beef cattle production in Indonesia—A review. *Asian-Australasian Journal of Animal Sciences*, 31(7), 976–983. <https://doi.org/10.5713/ajas.18.0233>
- Ansari, M. (2021). The environmental challenges arising from chemical pesticide overuse. *Outlooks on Pest Management*, 32(6), 247–248. https://doi.org/10.1564/v32_dec_05

- Asai, M., Moraine, M., Ryschawy, J., De Wit, J., Hoshide, A. K., & Martin, G. (2018). Critical factors for crop-livestock integration beyond the farm level: A cross-analysis of worldwide case studies. *Land use policy*, 73, 184–194. <https://doi.org/10.1016/j.landusepol.2017.12.010>
- Asmara, A., Purnamadewi, Y. L., Rindayanti, W., Achsani, M. N. F., Abdullah, A., Fadhillah, N., & Fitri, T. A. (2025). The analysis of dairy farming efficiency in East Java: Evidence post the foot and mouth disease outbreak. *Jurnal Manajemen & Agribisnis*, 22(1), 65–78. <https://doi.org/10.17358/jma.22.1.65>
- Asmara, A., Purnamadewi, Y. L., Rindayanti, W., Faaiz Achsani, M. N., Abdullah, A., Fadhillah, N., & Fitri, T. A. (2025). The Analysis of Dairy Farming Efficiency in East Java: Evidence Post The Foot and Mouth Disease Outbreak. *Journal of Management & Agribusiness/Jurnal Manajemen & Agribisnis*, 22(1). DOI: 10.17358/jma.22.1.65
- Bangert, E. A., & Wheeler, M. B. (2025). Assisted reproductive technologies and genetic improvement strategies for enhancing livestock production and food security in Tropical East Africa: A review. *Journal of Scientific Agriculture*, 9, 189–203. <https://doi.org/10.25081/jsa.2025.v9.9599>
- Bardhan, D. (2024). Rapporteur's Report on Sustaining Livelihoods: The Role of Livestock, Poultry and Fisheries in Rural Economy. *Indian Journal of Agricultural Economics*, 79(3), 874–887. DOI:10.63040/25827510.2024.03.036
- Besenfelder, U., & Havlicek, V. (2023). The interaction between the environment and embryo development in assisted reproduction. *Animal reproduction*, 20, e20230034. <https://doi.org/10.1590/1984-3143-AR2023-0034>
- Bulletti, F. M., Sciorio, R., Conforti, A., De Luca, R., Bulletti, C., Palagiano, A., Berrettini, M., Scaravelli, G., & Pierson, R. A. (2025). Causes of embryo implantation failure: A systematic review and metaanalysis of procedures to increase embryo implantation potential. *Frontiers in endocrinology*, 15, 1429193. <https://doi.org/10.3389/fendo.2024.1429193>
- Cao, B., Qin, J., Pan, B., Qazi, I. H., Ye, J., Fang, Y., & Zhou, G. (2022). Oxidative stress and oocyte cryopreservation: recent advances in mitigation strategies involving antioxidants. *Cells*, 11(22), 3573. <https://doi.org/10.3390/cells11223573>
- Contreras, D. A., Galina, C. S., & Chenoweth, P. (2021). Prospects for increasing the utilization of cattle embryo transfer by small-scale milk and meat producers in tropical regions. *Reproduction in Domestic Animals*, 56(12), 1479–1485. <https://doi.org/10.1111/rda.14015>
- D'Angelo, A., Panayotidis, C., Alteri, A., Mcheik, S., & Veleva, Z. (2022). Evidence and consensus on technical aspects of embryo transfer. *Human reproduction open*, 2022(4), hoac038. <https://doi.org/10.1093/hropen/hoac038>
- Enciso, K., Triana, N., Díaz, M., & Burkart, S. (2022). On (dis) connections and transformations: the role of the agricultural innovation system in the adoption of improved forages in Colombia. *Frontiers in Sustainable Food Systems*, 5, 741057. <https://doi.org/10.3389/fsufs.2021.741057>
- Fahrurrozy, M. A., Ammar, A. A., Arifin, N. A., Mentari, A., Tika B, E. M., Azzahra, P., Amin R, R., Azhary, A., Putri, A., Gasali, M., & Suherman. (2021). Pembuatan Sarabba Susu Sapi sebagai produk unggulan Desa Cendana. *Jurnal Dedikasi Masyarakat*, 5(1), 9–16. <https://doi.org/10.31850/jdm.v5i1.3234>

- Fernando, L., Cano, G., Lía, G., Mendoza, O., Guzmán, S. M., Tapasco, A. D., & Quintero, J. I. (2023). Agricultural innovation systems: Analysis from the subsystems of research and development, training, extension, and sustainability. *Frontiers in Sustainable Food Systems*, 7, 1–17. <https://doi.org/10.3389/fsufs.2023.1176366>
- Ferraz, J. B. S., Felício, P. E., Machado, P. F., & Mourão, G. B. (2016). Brazilian livestock and genetic improvement. *Animal Frontiers*, 6(4), 18–23.
- Freudenreich, H., Aladysheva, A., & Brück, T. (2022). Weather shocks across seasons and child health: Evidence from a panel study in the Kyrgyz Republic. *World Development*, 155, 105801. <https://doi.org/10.1016/j.worlddev.2021.105801>
- Gutiérrez Cano, L. F., Zарtha Sossa, J. W., Orozco Mendoza, G. L., Suárez Guzmán, L. M., Agudelo Tapasco, D. A., & Quintero Saavedra, J. I. (2023). Agricultural innovation system: analysis from the subsystems of R&D, training, extension, and sustainability. *Frontiers in Sustainable Food Systems*, 7, 1176366. <https://doi.org/10.3389/fsufs.2023.1176366>
- Hansen, P. J. (2020). The incompletely fulfilled promise of embryo transfer in cattle: Why aren't pregnancy rates greater and what can we do about it? *Journal of Animal Science*, 98(11), 1–20. <https://doi.org/10.1093/jas/skaa288>
- Hasler, J. F. (2014). Forty years of embryo transfer in cattle: A review focusing on the journal *Theriogenology*, the growth of the industry in North America, and personal reminiscences. *Theriogenology*, 81(1), 152–169. <https://doi.org/10.1016/j.theriogenology.2013.09.010>
- Hew, Y., Kutuk, D., Duzcu, T., Ergun, Y., & Basar, M. (2024). Artificial intelligence in IVF laboratories: elevating outcomes through precision and efficiency. *Biology*, 13(12), 988. <https://doi.org/10.3390/biology13120988>
- Huang, J. Y., Chen, H. Y., Tan, S. L., & Chian, R. C. (2006). Effects of osmotic stress and cryoprotectant toxicity on mouse oocyte fertilization and subsequent embryonic development in vitro. *Cell Preservation Technology*, 4(3), 149–160. <https://doi.org/10.1089/cpt.2006.4.149>
- Jenkins, W. M., Trindade, L. M., Pyett, S., van Mierlo, B., Welch, D., & van Zanten, H. H. (2024). Will the protein transition lead to sustainable food systems?. *Global Food Security*, 43, 100809. <https://doi.org/10.1016/j.gfs.2024.100809>
- Kedang, V. M. K., Permatasari, I., Chanchaidechachai, T., & Inchaisri, C. (2025). Spatial-temporal distribution and risk factors of foot and mouth disease outbreaks in Java Island, Indonesia from 2022 to 2023. *BMC Veterinary Research*, 21(1), 180. <https://doi.org/10.1186/s12917-025-04621-2>
- Khade, S. B., Khillare, R. S., & Dastagiri, M. B. (2021). Global livestock development: Policies and vision. *Indian J. Anim. Sci*, 91(9), 770–779. <https://doi.org/10.56093/ijans.v91i9.116470>
- Khan, I., Mesalam, A., Heo, Y. S., Lee, S. H., Nabi, G., & Kong, I. K. (2023). Heat stress as a barrier to successful reproduction and potential alleviation strategies in cattle. *Animals*, 13(14), 2359. <https://doi.org/10.3390/ani13142359>
- Leroy, G., Besbes, B., Boettcher, P., Hoffmann, I., Pilling, D., Baumung, R., & Scherf, B. (2016). Factors and determinants of animal genetic resources management activities

- across the world. *Livestock Science*, 189, 70-77. <https://doi.org/10.1016/j.livsci.2016.05.006>
- Lestari, T. D., Ismudiono, I., & Sardjito, T. (2019). Breeding performance of Indonesian beef cattle as recipients for embryo transfer. *Journal of Veterinary Medical Science*, 81(11), 1688–1691. <https://doi.org/10.1292/jvms.19-0429>
- Marlina, I., Wibowo, G., Bastias, D. D., Sijapati Basnett, B., Prasetyo, D. D., & Nasiir, M. (2024). Counting the costs: Understanding the extra costs of living with disability in Indonesia to advance inclusive policies within the SDG framework. *Frontiers in Rehabilitation Sciences*, 5. <https://doi.org/10.3389/fresc.2024.1236365>
- Mueller, M. L., & Van Eenennaam, A. L. (2022). Synergistic power of genomic selection, assisted reproductive technologies, and gene editing to drive genetic improvement of cattle. *CABI Agriculture and Bioscience*, 3(1), 13. <https://doi.org/10.1186/s43170-022-00080-z>
- Priyanto, L., Nurdin, A. S., Ekowati, I. A., Maemunah, S., & Putranti, D. (2024). Pengaruh pasca penyakit mulut dan kuku (PMK) terhadap estrus dan kebuntingan sapi potong di Provinsi Jawa Timur. *Cannarium: Jurnal Ilmiah Peternakan*, 22(2), 4–6.
- Rahmatillah, R. S., Rahmat, D., & Dudi, D. (2024). Genetic quality improvement of beef cattle in Indonesia: Overview and prospects. *Jurnal Ilmiah Peternakan Terpadu*, 12(3), 258–271. <https://doi.org/10.23960/jipt.v12i3.p258-271>
- Rensis, F. D., Garcia-Ispuerto, I., & López-Gatius, F. (2015). Seasonal heat stress: Clinical implications and hormone treatments for the fertility of dairy cows. *Theriogenology*, 84(5), 659–666. <https://doi.org/10.1016/j.theriogenology.2015.04.021>
- Setyo, N., Humaidah, N., & Kentjonowaty, I. (2024). Kajian sapi peranakan Friesian Holstein (PFH) dengan riwayat penyakit mulut dan kuku (PMK) terhadap kejadian gangguan reproduksi. *Dinamika Rekasatwa*, 7(1), 381–384.
- Shortall, S., & Brown, D. L. (2019). Guest editorial: Thinking about rural inequalities as a cross-national research project. *Journal of Rural Studies*, 86, 213–218. <https://doi.org/10.1016/j.jrurstud.2019.04.001>
- Sini, I., Handayani, N., Pratiwi, A., Polim, A. A., & Boediono, A. (2020). Blastocyst elective single embryo transfer improves perinatal outcomes among women undergoing assisted reproductive technology in Indonesia. *Asian Pacific Journal of Reproduction*, 9(3), 118-123. DOI: 10.4103/2305-0500.284268
- Syahdan, R., Atabany, A., Komala, I., & Ningtias, P. I. (2025). Analysis of embryo transfer pregnancy rate from Friesian Holstein cow recipients in BET Cipelang. *Jurnal Ilmiah Peternakan Terpadu*, 13(2), 399–411. <https://doi.org/10.23960/jipt.v13i2.p399-411>
- Tangkas, M., Putra, I. M. M., & Endarwati, J. (2025). A predictive model for in vitro fertilization success: a retrospective cohort study from a tertiary clinic in Indonesia. *Indonesian Journal of Perinatology*, 6(2), 38-42. <https://doi.org/10.51559/inajperinatol.v6i2.84>
- Wu, G., Bazer, F. W., & Cross, H. R. (2014). Land-based production of animal protein: impacts, efficiency, and sustainability. *Annals of the New York Academy of Sciences*, 1328(1), 18-28. <https://doi.org/10.1111/nyas.12566>
- Yadav, J. N., Singh, H. K., Yadav, V., & Diwakar, R. P. (2025). Artificial insemination and embryo transfer: Emerging technologies in the livestock industry. *International*

Journal of Environment, Agriculture and Biotechnology, 10(2), 610868. DOI:
10.22161/ijeab