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Development Potential of Bali Cattle in South Sulawesi: A Study on Population Structure and Management System

Ahmad Alfaruqi Syahrandi Adam[1], *Muhammad* Yusuf[2*], *Sahiruddin* Sahiruddin[2], *Athhar Manabi* Diansyah[2], *Andi Muhammad* Alfian[2], *Masturi* Masturi[2], and *Syahruddin* Said[3]

[1]Graduated Student of Agricultural System, Graduate School, Hasanuddin University, Jl. Perintis Kemerdekaan Km. 10 Tamalanrea Makassar, South Sulawesi, 90245, Indonesia
[2]Faculty of Animal Science, Hasanuddin University, Jl. Perintis Kemerdekaan Km. 10 Tamalanrea Makassar, South Sulawesi, 90245, Indonesia
[3]Research Center of Applied Zoology, National Research and Innovation Agency, Cibinong Science Center, Jl. Raya Jakarta-Bogor, West Java, Indonesia.16915

Abstract. Bali cattle (Bos sondaicus) are one of Indonesia's native livestock breeds. They are valued for their ability to adapt, their rapid reproductive capacity, and their significant contribution to the country's beef supply. South Sulawesi is a significant region for the cultivation of this commodity, but most farms are small and productivity remains low. This study examined the relationships between population structure, management systems, and reproductive performance of Bali cattle in the region. A cross-sectional survey of 166 farmers (826 cattle) across five districts collected data via questionnaires, interviews, and on-farm observations, and was analysed using descriptive statistics. There were primarily female cattle, which means that targeted breeding could lead to a large herd. Natural mating (NM) was the primary method used in extensive and semi-intensive systems, whereas artificial insemination (AI) was the primary method employed in intensive systems. The calving rates were similar for all methods (58.33–59.09%), but AI had a better chance of improving genetic quality in controlled settings. These findings underscore the need for policy support and farmer training to promote the adoption of reproductive technologies, thereby enhancing the productivity, genetic merit, and sustainability of Bali cattle farming in South Sulawesi.

1 Introduction

Bali cattle (Bos sondaicus) are one of Indonesia's indigenous livestock germplasm that strategically support national food security, especially in the livestock sector. Bali cattle's advantages include high adaptation to the tropical environment, good reproductive efficiency, and relatively high feed conversion ability, making Bali cattle a commodity that supports the fulfilment of meat needs in Indonesia. South Sulawesi is one of the centres of beef cattle development in Indonesia. According to data from the Central Statistics Agency

* Corresponding author: myusuf@unhas.ac.id

(BPS) in 2024, the beef cattle population in South Sulawesi reached 1,414,067 heads. However, to date, domestic demand for meat has not been fully met, resulting in continued meat imports.. Smallholder farms dominate the sector, often characterized by low adoption of advanced breeding technologies and limited access to superior sires, both of which constrain productivity gains. Therefore, a deeper understanding of the condition of Bali cattle farming in South Sulawesi is necessary, based on the results presented and factors related to livestock productivity, such as population structure, management systems, and reproductive management.

Previous studies have examined Bali cattle from various perspectives, including reproductive disorders, marketing efficiency, and genetic traits. However, few have integrated analysis of population structure, management systems, and reproductive strategies within a single framework. This integration is crucial for comprehending the interplay between herd demographics, husbandry practices, and breeding methods in affecting productivity and genetic sustainability.

Examining the structure of a population can provide insight into the genetic dynamics of a herd, which can inform targeted breeding strategies. Additionally, management systems and mating methods have a direct impact on reproductive success and genetic improvement. However, there is a lack of region-specific evidence on how these factors shape the development potential of Bali cattle in South Sulawesi, where traditional practices remain prevalent. Therefore, this study aims to assess the relationships between population structure, management systems, and reproductive performance of Bali cattle in South Sulawesi. These findings are expected to form the basis for developing effective policy strategies to enhance productivity, improve genetic quality, and ensure the sustainable development of Indonesia's native cattle genetic resources.

2 Materials and Method

2.1 Research design

This study used a cross-sectional field survey to collect primary data on the structure of the Bali cattle population, management practices, and reproductive performance. The instruments for data collection included structured questionnaires, face-to-face interviews, and direct on-farm observations. The choice of this design allowed for a comprehensive snapshot of current farming conditions across multiple locations in South Sulawesi.

2.2 Sampling method and population

This study involved 166 farmers with 826 livestock spread across several districts: Gowa (n = 148), Maros (n = 117), Barru (n = 258), Bone (n = 147), and Sinjai (n = 156). Purposive sampling techniques were employed to ensure that respondents met the study's criteria, specifically that they had been actively involved in Balinese cattle farming for at least the past five years and were willing to participate in the survey. This approach was chosen to maximize the relevance of the data based on the experience and knowledge of livestock management practices among farmers..

The data collection process was carried out using a questionnaire instrument. The questionnaire was divided into two parts. The first part contained questions about the structure of the Bali cattle population owned by the farmer, including the number of cattle, their sex and age categories, and the health condition of the cattle. The second part focuses on the management systems implemented by farmers, including housing and routine health care for their livestock. To capture the diversity of agricultural contexts, the questionnaire was distributed in two formats: direct visits to farms in accessible areas and online forms for farmers in hard-to-reach places. This dual-mode approach facilitated broader coverage and inclusivity, ensuring that both traditional and more technology-adaptive farmers were represented.

2.3 Research variable

The variables studied in this study are as follows:

1. The number of offspring <12 months old was counted to compare between males and females.
2. The number of young cattle aged 12-24 months was calculated based on the ratio of males and females.
3. The number of adult cattle (over 24 months old) is calculated based on the ratio of males to females.
4. A Management system is applied to calculate the comparison of the application of Intensive, Semi-Intensive, and Extensive methods.
5. Mating method applied to calculate the comparison of the application of Artificial Insemination (AI), Natural Mating (NM), or both.

2.4 Data analysis

All data obtained will be tabulated and analyzed using Microsoft Excel software to ensure accuracy and consistency. Descriptive statistics—including frequency distributions, percentages, and measures of central tendency—were applied to characterise the population structure, management systems, and mating methods. Cross-tabulation was used to identify patterns and associations between management types and reproductive practices, while graphical representations were prepared to enhance clarity and facilitate interpretation.

3 Results and Discussion

3.1 Population structure of Bali cattle in South Sulawesi

Population structure refers to the balance of the livestock population within a community. It also needs to be observed as a basis for determining policy directions supporting a commodity's development. Based on the survey, the population structure of Bali cattle in South Sulawesi is shown in Figure 1.

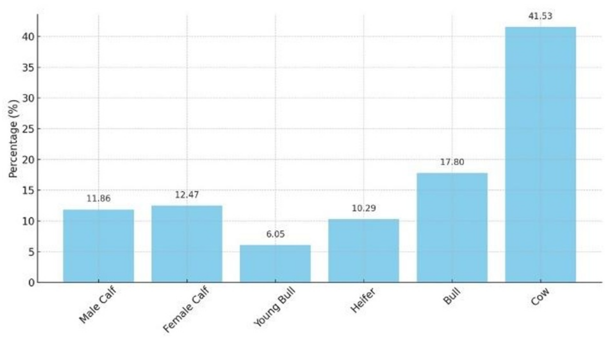

Fig. 1. Population structure of Bali cattle in South Sulawesi, expressed as percentage distribution by age category (<12 months, 12–24 months, >24 months) and sex.

Figure 1 shows that female cattle dominated the Bali cattle population across all age categories in South Sulawesi. The proportion of female calves (<12 months) was 12.47% compared to 11.86% for males, while young females (12–24 months) comprised 10.29% compared to 6.05% for young males. Among adults (>24 months), females accounted for 41.53% and males for 17.80% of the population. This distribution pattern was consistent across the five districts surveyed.

The dominance of adult females provides a strategic advantage for population growth, given that dams serve as the core reproductive capital of the livestock system. With the implementation of proper reproductive management, including synchronisation programs, selective breeding, and postpartum care, the population can now serve as a solid foundation for accelerating population growth. This aligns with the findings of Zhang et al. [9], who emphasise the importance of leveraging adult females to enhance productivity and genetic resilience within cattle populations.

Conversely, the proportion of adult and young males is relatively low. This reflects the common practice among small farmers to sell male cattle earlier due to their high market value and faster income Although this strategy meets the short-term economic needs of farmers, it can reduce the availability of superior males for natural mating, potentially hindering genetic progress in the population development process. On the other hand, the presence of young female.

Maintaining stable growth in the calf category (<12 months) is equally important, as this stage lays the foundation for supporting a sustainable population in the future. Adequate nutritional needs, disease prevention, and proper management practices in the early stages of life are essential to ensure optimal growth is maintained, thereby guaranteeing the availability of quality livestock for breeding and fattening purposes. The focus on the population structure of calves aligns with the recommendations of Clinquart et al. [1], who emphasise that management in the early stages of life has a long-term impact on meat quality, reproductive efficiency, and herd productivity.

3.2 The relationship between the application of management systems and mating methods

To increase livestock productivity, particularly in Bali cattle, implementing effective reproductive management and management systems is crucial for determining reproductive success. The combination of traditional and modern approaches in reproductive management requires study to understand the trends and challenges faced by farmers in the field. Therefore, analysing the relationship between the management system and reproductive management, particularly mating methods, is crucial for formulating a more effective and sustainable development strategy. Based on the survey results, the relationship between the implementation of the management system and mating methods is presented in Table 1.

Table 1. Proportion (%) of mating methods used by management systems in Bali cattle farms, based on survey data from South Sulawesi.

Mating Method	AI (%)	NM (%)	Both (%)
Extensive	0.00	100.00	0.00
Intensive	62.22	22.22	15.56
Semi-Intensive	11.11	53.13	35.76

Note: AI= Artificial Insemination; NM= Natural Mating.

The survey results show apparent differences in the application of mating methods across various management systems. In extensive systems, NM is used exclusively (100%), while in intensive systems, AI dominates (62.22%), followed by NM (22.22%) and a combination of AI and NM (15.56%). In semi-intensive systems, farmers more frequently apply a combination of AI and NM (53.13%), followed by NM (35.76%) and AI (11.11%).

The dominance of NM in extensive systems reflects clear evidence of traditional husbandry practices among smallholder farmers. These systems typically rely on natural grazing with minimal intervention and are considered cost-effective and suitable given local resource constraints. In fact, previous studies have shown that reliance on NM methods in extensive conditions often leads to longer birth intervals and reduced reproductive efficiency indicating that reproductive potential is not fully realized in such contexts [2]. In intensive systems, higher AI adoption rates are closely linked to controlled livestock rearing environments, better access to extension services, and farmers' awareness of genetic improvement. The use of AI in these systems not only reduces dependence on local bulls but also increases the chances of producing cattle with superior genetic material. Previous research has emphasized that technology-driven breeding can accelerate genetic progress and improve herd quality. However, barriers such as service availability and costs remain challenges for broader AI adoption, particularly among smallholder farmers and in hard-to-reach areas.

The semi-intensive system demonstrates the application of NM and AI breeding methods. Farmers in this category generally integrate cattle farming with agriculture, particularly rice farming. This method allows animals to graze after harvest while still receiving supplementary feed. The application of a combination of NM and AI highlights both the opportunities and challenges in implementing this system. The application of AI demonstrates farmers' openness to innovation and agricultural technology, while dependence on NM will continue due to limited resources and land ownership patterns. Similar dynamics are also observed in other small-scale agricultural systems, where semi-intensive agriculture is viewed as a transitional stage toward more technology-adaptive agricultural practices [3,4]. Policy measures supporting training, semen accessibility, and extension services can enhance AI adoption without disrupting existing farming routines. Research by Pugliese et al. [5] also supports the idea that the implementation of semi-intensive systems is more efficient in terms of resource use and more welfare-oriented than extensive systems. However, intensive systems are still not entirely applicable. Specifically for Bali cattle, Sumadiasa et al. [6] found that cattle raised in semi-intensive systems showed better reproductive performance than those in extensive systems. However, in areas where the NM system is still dominant, the lack of bulls with superior genetics owned by farmers continues to limit productivity [7]. Policy interventions to improve farmers' access to superior bulls by implementing AI are crucial to enhancing reproductive efficiency in this mixed farming system.

3.3 The relationship between mating method and calving rate

A critical indicator in evaluating the reproductive performance of livestock is the calving rate, which reflects the efficiency of the mating method applied. In addition, the sex proportion of calves produced has direct implications for population development strategies, especially in local livestock such as Bali cattle. Based on the survey results, the relationship between the application of mating methods and births in Balinese cattle is presented in Figure 2.

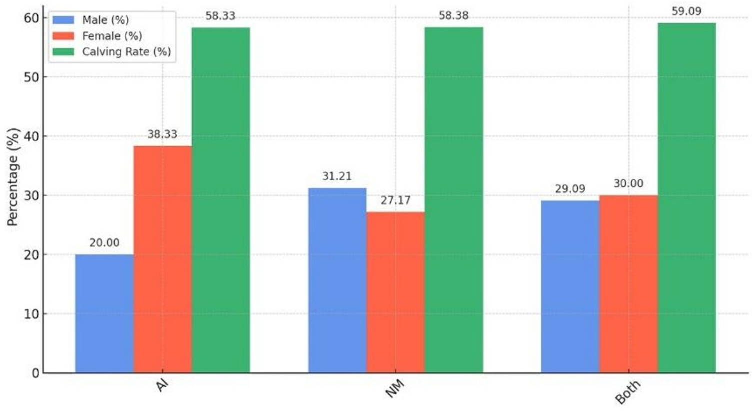

Fig. 2. Calving rate (%) and calf sex ratio (male, female) by mating method based on one-year reproductive performance.

The survey showed that calf birth rates were relatively consistent across the three breeding methods, with insignificant differences: 58.33% for AI, 58.38% for NM, and 59.09% for the combined method. Although overall reproductive success appeared similar, the distribution of calf sex differed significantly. Artificial insemination produces a higher proportion of female calves (38.33%) compared to males (20.00%), while natural mating tends to produce more male calves (31.21%) than females (27.17%). The combined method yielded the most balanced results, with 29.09% males and 30.00% females.

The consistency in calf birth rates across all three mating methods indicates that the reproductive adaptability of Bali cattle remains strong despite varying management practices. Adaptability is a key parameter and primary advantage in small-scale livestock systems, where resource availability and technical support are often limited. However, beyond overall reproductive success, differences in the sex ratio of calves produced raise important strategic considerations. The dominance of female calves in artificial insemination (AI) applications shows that this method can support population growth more effectively, as it increases the number of potential replacement females, in line with the findings of Pardo et al. [8] that reproductive technology can be strategically utilized to increase the chances of population growth.

Conversely, NM shows a tendency to produce more male calves. Although this result may be economically beneficial for fattening and marketing purposes, it may limit livestock population growth if the availability of females becomes inadequate, thereby impacting the level of sustainable farming. Unlike the previous discussion, which focused on bull ownership, the implications here are demographic: continued reliance on NM risks reinforcing the dominant production of male calves, which may not necessarily have good genetic quality, thereby hindering progress in population growth and genetic improvement. Yousuf [9] further emphasizes that NM not only limits genetic progress but also increases the risk of reproductive disease transmission compared to AI.

The use of a combination of AI and NM, although the difference is not significant, shows the highest birth rate and a more balanced sex ratio. However, these results must be interpreted with caution, because continuous reliance on NM without regard to the quality of the stallion results in uncertain genetic quality of the offspring. For now, the adoption of this combined method reflects farmers' openness to integrating reproductive technology with traditional practices that remain difficult to abandon. This openness is important as it can serve as an entry point for the gradual adoption of advanced reproductive biotechnology—such as sexed semen and estrus synchronization—which has been shown to accelerate genetic progress when combined with farmer training [10]. In addition, Mueller et al. [11] argue that AI contributes not only to genetic improvement but also to better growth performance in calves, a combination that current methods cannot yet guarantee. This has been confirmed by similar, more specific research on Bali cattle, which shows that calves produced through the application of AI have better body dimensions and weight compared to those receiving NM [12]. Therefore, while combined methods signify a transitional stage, their success ultimately depends on how well modern technology can be integrated into farmer practices.

However, this study still has limitations that need to be acknowledged. The analysis still focuses primarily on population-level indicators, such as birth rates, sex ratios, and population structure, without capturing more detailed reproductive characteristics, including conception rates, birth intervals, postpartum anestrus, or calf survival. Furthermore, this assessment does not include an evaluation of genetic quality in offspring, which is essential for understanding the long-term impact of various breeding strategies. As emphasised by Pian et al. [13] and Priyono et al. [14], comprehensive reproductive and genetic evaluations are crucial for informing effective breeding interventions. Future research is expected to combine reproductive performance metrics and genetic profiles to provide a more comprehensive understanding of how breeding methods influence not only population structure but also productivity and genetic sustainability.

4 Conclusion

In conclusion, the dominance of females in the population structure highlights the potential for Bali cattle development in South Sulawesi, particularly through population growth. Extensive and semi-intensive management systems rely on NM, while intensive systems prefer AI supported by a more controlled rearing environment. Calving rates of Bali cattle in the past year showed similar results between NM and AI mating methods. However, the application of reproductive technologies, such as AI, has been proven to improve genetic quality, increasing the productivity and sustainability of Bali cattle development. Therefore, policy support is necessary to encourage farmers' full adoption of technology and achieve maximum productivity.

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