*Review Article*

# Reproductive performances of Bali cattle under different management systems for designing their breeding strategies

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*Abstract*

Reproductive performance is an economically important trait in beef cattle breeding and improvement programs, as it directly influences overall productivity. Key performance indicators, such as age at puberty (AP), age at first mating (AFM), age at first calving (AFC), calving intervals (CI), days open (DO), number of services per conception (NSC), conception rate (CR), and gestation length (GL), can be used to assess reproductive performance. This review summarized findings from previous studies on the reproductive performance of Bali cattle under various management conditions in Indonesia. The literature indicated a range of reproductive performances in Bali cattle, with AP varying from 15.60 to 26.03 months, AFM from 16.90 to 34.08 months, AFC from 26.61 to 43.56 months, CI from 11.17 to 15.11 months, DO from 69.35 to 401.50 days, NSC from 1.00 to 2.70, CR from 33.70% to 83.00%, and GL from 275.58 to 288.96 days. The review emphasized key reproductive traits that require attention, specifically AFC and CI. While most reproductive traits are significantly influenced by environmental factors, this review demonstrated notable variation in reproductive characteristics across different management practices and populations. Consequently, management interventions and selection strategies could improve reproductive performance. Additionally, livestock keepers should monitor their cows regularly and receive training on reproductive management. Policymakers should invest in education and training for farmers, as workshops and seminars can provide essential knowledge on reproductive technologies, estrus detection, and artificial insemination techniques. This comprehensive approach is expected to enhance productivity and reproductive efficiency, ultimately increasing economic benefits for farmers.

**Keywords:** breeding scheme, fertility, indigenous cattle, Indonesia, reproduction

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## *Introduction*

Livestock play a significant role in rural livelihoods across many developing countries, offering both direct and indirect benefits to communities. In Indonesia, cattle have diverse and evolving functions within rural households. They offer various benefits, including food, income, fertilizer, traction, and transportation, while also supporting economic stability and improving social status. According to recent data from the Directorate General of Livestock and Animal Health, Indonesia is home to approximately 16 million cattle (Ditjenpkh, 2023), which comprise three primary breeds: zebu cattle (*Bos indicus*), Bali cattle (*Bos javanicus*), and taurine cattle (*Bos taurus*).

In Indonesia, approximately 90% of the country's cattle production is run by smallholder farmers, encompassing around 6.5 million farmers living in rural areas, while the remaining 10% is run by more commercial farmers (Agus and Widi, 2018). Among the three cattle breeds, Bali cattle represent 27% of the total cattle population in the country and are regarded as the most important breed for smallholder farmers. Additionally, this breed holds evolutionary significance as a direct descendant of the Banteng (Purwantara *et al.*, 2012). Bali cattle, indigenous to Indonesia, are primarily found on the island of Bali, although they can also be found in Malaysia, the Philippines, and Australia (Nijman *et al.*, 2003). Bali cattle are smaller than other *Bos indicus* and *Bos taurus* breeds. Although comprehensive breed comparisons are not yet available, it can be inferred that *Bos javanicus* cattle are well suited to Indonesian tropical beef production systems and demonstrate high productivity (Widyas *et al.*, 2022), exhibiting substantial growth rates even on low-quality feed (Sutarno and Setyawan, 2016).

Considering their significance, evaluating economically important traits related to reproductive efficiency and productivity is essential for developing a sustainable breeding program for the breed, thereby aligning with breed improvement and animal breeder objectives (Roy *et al.*, 2024). Reproduction should be integrated into breeding goals, as it is one of the economic traits associated with the fertility, fitness, health, and survival of the animals. Indicators of reproductive potential, such as the age at puberty (AP), age at first mating (AFM), age at first calving (AFC), calving interval (CI), days open (DO), number of services per conception (NSC), conception rate (CR), and gestation length (GL) are important determinants of animal fertility (Gottschall *et al.*, 2007; Diskin and Kenny, 2014). Day and Nogueira (2013) reported that heifers that calved for the first time at two years of age produced, on average, 0.7 more calves by 6.5 years of age compared to those that first calved at three years of age. Moreover, the reproductive success of heifers during their first calving period is closely related to their lifetime reproductive efficiency (Cushman *et al.*, 2013). Higher pregnancy rates positively influence annual income per cow (Ríos-Mohar *et al.*, 2022). Although numerous studies have made their own efforts to assess the reproductive performance of Bali indigenous cattle across various regions of Indonesia, there is a lack of comprehensive studies comparing different management systems on Bali cattle reproductive traits. Research has shown that the reproductive performance of beef cattle is significantly affected by various management conditions, as well as the social status, education levels, and experience of farm owners (Ali *et al.*, 2015; Henley *et al.*, 2020). Thus, performance evaluations should consider not only individual cows but also herd and overall management practices. In addition, compiled information is required to easily understand the current status of Bali cattle production. The primary objective of this paper is to review and document the reproductive performances of Bali cattle under varying management conditions to inform breeding strategy development.

### *Reproductive performances of Bali indigenous cattle*

***Age at puberty:*** *The* age at which heifers reach puberty serves as an indicator of their reproductive potential and can impact their subsequent reproductive performance. Therefore, advancing puberty and sexual maturity in cattle is crucial for the reproductive efficiency and economic sustainability of global cattle production systems (Kenny *et al.*, 2017). Puberty marks the stage when reproductive organs are fully developed, enabling the animal to release gametes (Gupta *et al.*, 2016). In heifers, puberty results from the interplay of genetics and nutrition both before and after weaning. Achieving early puberty is vital to meet the herd's primary reproductive objective: first calving at 2 years of age (Diskin and Kenny, 2014).

Most heifers reach puberty between 8 and 10 months of age (Gasser *et al.*, 2006). Table 1 presents the average AP for various populations of Bali indigenous cattle raised under different management conditions. The earliest AP, reported as 15.60 months, was observed in Bali cattle raised in pasture and plantation agroecosystems on Timor Island, East Nusa Tenggara province (Habaora *et al.*, 2019). In contrast, the latest AP was recorded at 26.03 months for Bali cattle under extensive management conditions in Bima and Dompu regency, West Nusa Tenggara province (Prasetya *et al.*, 2022). The average AP (months) of 16.56-23.76 (Budisatria *et al.*, 2021; Hidayat *et al.*, 2021), 16.02-23.04 (Budisatria *et al.*, 2021; Hidayat *et al.*, 2021), and 16.03-26.03 (Hidayat *et al.*, 2021; Prasetya *et al.*, 2022) for Bali cattle under intensive, semi-intensive, and extensive management conditions, respectively, was reported. These values were higher than 12.20-14.53 months reported in Aceh cattle from Aceh Jaya regency, Aceh province (Novita *et al.*, 2023) and were comparable with 19.00-21.90 months reported in Ongole grade cattle from North Minahasa regency, North Sulawesi province (Napitupulu *et al.*, 2024).

**Table 1** The age at puberty (months) of Bali indigenous cattle under varying management conditions across Indonesia

| Management Condition | Study Area | Age at Puberty (Months) | References |
|---|---|---|---|
| Intensive | Buleleng regency, Bali province | 22.09 | (Mahasanti *et al.*, 2021) |
| Intensive | Badung regency, Bali province | 21.44 | (Prananda *et al.*, 2022) |
| Intensive | Badung regency, Bali province | 21.44 | (Heryani *et al.*, 2019) |
| Intensive | Badung regency, Bali province | 21.61 | (Pridayanti *et al.*, 2021) |
| Intensive | Badung regency, Bali province | 18.26 | (Wimbavitrati *et al.*, 2020) |
| Intensive | Jembrana regency, Bali province | 23.64 | (Siswanto *et al.*, 2013) |
| Intensive | South Konawe regency, Southeast Sulawesi province | 23.76 | (Budisatria *et al.*, 2021) |
| Intensive | Central Bangka regency, Bangka Belitung Islands province | 16.56 | (Hidayat *et al.*, 2021) |
| Semi-intensive | Bima Regency, West Nusa Tenggara province | 16.97 | (Sumadiasa *et al.*, 2024) |
| Semi-intensive | South Konawe regency, Southeast Sulawesi province | 23.04 | (Budisatria *et al.*, 2021) |
| Semi-intensive | Central Bangka regency, Bangka Belitung Islands province | 16.02 | (Hidayat *et al.*, 2021) |
| Extensive | Bima and Dompu regency, West Nusa Tenggara province | 26.03 | (Prasetya *et al.*, 2022) |
| Extensive | Central Bangka regency, Bangka Belitung Islands province | 16.03 | (Hidayat *et al.*, 2021) |
| Extensive | Bima regency, West Nusa Tenggara provine | 19.94 | (Sumadiasa *et al.*, 2024) |
| Plantation agroecosystem | Timor Island, East Nusa Tenggara province | 15.60 | (Habaora *et al.*, 2019) |
| Agriculture agroecosystem | Timor Island, East Nusa Tenggara province | 16.80 | (Habaora *et al.*, 2019) |
| Forest agroecosystem | Timor Island, East Nusa Tenggara province | 16.80 | (Habaora *et al.*, 2019) |

The AP and fertility in heifers is generally influenced by nutrition and genetics, which determine the age at first calving for individual animals (Day and Nogueira, 2013). Management conditions and geographical locations have been shown to affect reproductive performance. For example, the AP for Bali cattle under extensive systems was reported at 19.94 months, while it decreased to 16.97 months under semi-intensive systems (Sumadiasa *et al.*, 2024). Meanwhile, Bali cattle raised in Timor Island, East Nusa Tenggara province (Habaora *et al.*, 2019) have generally lower AP as compared to those raised in Bali Island, Bali province (Heryani *et al.*, 2019; Mahasanti *et al.*, 2021; Pridayanti *et al.*, 2021; Prananda *et al.*, 2022). The AP is regulated by a complex array of biochemical processes that involve interactions among key metabolic, neuroendocrine, and reproductive tissues (Kenny *et al.*, 2017) and is significantly influenced by nutrition, age, and genetics (Perry, 2016). Most research to date has concentrated on nutritional changes post-weaning and their effects on puberty. It has been reported that feed supplements to heifers can reduce AP and increase body weight (Severino-Lendechy *et al.*, 2020). Heifers with lower weights typically attain puberty at an older age (Perry, 2016), indicating that undernutrition can postpone the onset of puberty. Studies evaluating the effects of preweaning weight gain on reproductive development and pubertal status have demonstrated that weaning heifers at 2–4 months of age and providing them with a concentrated diet can enhance pubertal status (Gasser *et al.*, 2006).

The AP is regarded as moderately heritable, with estimates ranging from 0.33 (Gasser *et al.*, 2006) to 0.40 (Martin *et al.*, 1992). Consequently, specific genes that affect the AP in heifers can be identified. Heritability estimates indicate that enhancing heifer reproductive performance may be feasible by focusing on these particular genes and/or pathways. Selecting for an earlier AP has been associated with increased pregnancy rates and a decrease in days to calving (Morris *et al.*, 2000). Heifers that experience puberty at an earlier age are often more productive over their lifetime. Given the moderate heritability of AP, selection should successfully decrease the days to puberty, thereby enhancing heifer productivity and profitability (Engle *et al.*, 2019).

***Age at first mating:*** The AFM in cattle production is a key factor affecting reproductive efficiency and the overall productivity of pastoral systems. This parameter affects not only the lifetime productivity of heifers but also the overall economic performance of a farm (El-Naser *et al.*, 2020). Research indicates that achieving the ideal AFM can enhance calf survival, improve weight gain, and improve the overall productivity of indigenous cattle breeds (Nilforooshan and Edriss, 2004). Consequently, understanding and promoting the optimal AFM is important for sustaining indigenous cattle farming systems.

The AFM for Bali indigenous cattle under various management conditions is summarized in Table 2. Generally, the earliest AFM (16.90 months) was reported in Bali cattle raised under extensive production systems in Central Bangka regency, Bangka Belitung Islands province (Hidayat *et al.*, 2021), while the latest age (34.08 months) was noted for Bali cattle under the intensive management conditions in South Konawe regency, Southeast Sulawesi province (Budisatria *et al.*, 2021). Reports indicated that Bali cattle are typically mated between 18.50 (Hidayat *et al.*, 2021) and 34.08 (Budisatria *et al.*, 2021) months of age under intensive production system, between 17.48 (Hidayat *et al.*, 2021) and 33.24 (Budisatria *et al.*, 2021) months of age under semi-extensive conditions, and at 16.90 months of age under extensive production system (Hidayat *et al.*, 2021), depending on the management practices (Prasetya *et al.*, 2022). The reported values were comparable to those of other indigenous cattle in Indonesia, including Madura cattle in Pasuruan regency, East Java province (23.20 months) (Hartati *et al.*, 2021), Aceh cattle in Aceh Besar regency, Aceh province (23.80 months) (Bakhtiar *et al.*, 2015), and Ongole grade cattle in North Minahasa regency, North Sulawesi province (22.84 months) (Sumiyanti *et al.*, 2023).

**Table 2** The age at first mating (months) of Bali indigenous cattle under varying management conditions across Indonesia

| Management Condition | Study Area | Age at First Mating (Months) | References |
|---|---|---|---|
| Pasture agroecosystem | Timor Island, East Nusa Tenggara province | 22.80 | (Habaora *et al.*, 2019) |
| Plantation agroecosystem | Timor Island, East Nusa Tenggara province | 24.00 | (Habaora *et al.*, 2019) |
| Agriculture agroecosystem | Timor Island, East Nusa Tenggara province | 20.40 | (Habaora *et al.*, 2019) |
| Forest agroecosystem | Timor Island, East Nusa Tenggara province | 21.60 | (Habaora *et al.*, 2019) |
| Intensive | South Konawe regency, Southeast Sulawesi province | 34.08 | (Budisatria *et al.*, 2021) |
| Intensive | Badung regency, Bali province | 22.46 | (Wimbavitrati *et al.*, 2020) |
| Intensive | Central Bangka regency, Bangka Belitung Islands province | 18.50 | (Hidayat *et al.*, 2021) |
| Semi-intensive | Central Bangka regency, Bangka Belitung Islands province | 17.48 | (Hidayat *et al.*, 2021) |
| Semi-intensive | South Konawe regency, Southeast Sulawesi province | 33.24 | (Budisatria *et al.*, 2021) |
| Extensive | Bima and Dompu regency, West Nusa Tenggara province | 26.55 | (Prasetya *et al.*, 2022) |
| Extensive | Central Bangka regency, Bangka Belitung Islands province | 16.90 | (Hidayat *et al.*, 2021) |

The reported values indicated that Bali cattle exhibit greater variation in AFM across varying management conditions. The ideal AFM in mammals is influenced by genotype, nutrition, housing systems, and management practices (Tummaruk *et al.*, 2000; Lohakare *et al.*, 2012). Optimal AFM can be achieved by modifying growth rates, which are affected by genetic potential, nutrition, and environmental factors. The relationship between body growth, subsequent fertility, and meat production is crucial for the overall economic assessment of short-term rearing (Mourits *et al.*, 2000). Rincker *et al.* (2011) reported that intensified feeding of calves can reduce AP, which subsequently affects the AFM. Earlier AP in boar is correlated with a younger AFM and a shorter non-productive period before entering the breeding herd (van Wettere *et al.*, 2006). Several studies highlighted the impact of geographical location on AFM. For instance, Bali cattle in South Konawe regency, Southeast Sulawesi province, under intensive management had an AFC of 34.08 months (Budisatria *et al.*, 2021), whereas it decreased to 18.50 months in Central Bangka regency, Bangka Belitung Islands province under similar management condition (Hidayat *et al.*, 2021).

***Age at first calving:*** The AFC refers to the age at which a heifer gives birth to its first calf, ideally at 24 months of age (Nilforooshan and Edriss, 2004). Achieving this ideal age is influenced by numerous factors, such as breed, nutrition, climatic conditions, and management practices (Garcia-Peniche *et al.*, 2005; Twomey and Cromie, 2023), all of which significantly affect reproductive performance and lifetime productivity. Optimizing AFC not only improves the productivity of individual animals but also contributes to the overall sustainability and profitability of farms (Twomey and Cromie, 2023). Heifers that calve at a younger age typically enter the breeding herd earlier, allowing for more opportunities to produce calves throughout their lifetime. In contrast, delays in achieving a timely AFC can lead to economic drawbacks. Late calving in heifers can result in increased feed costs and management resources without yielding corresponding reproductive benefits. López-Paredes *et al.* (2018) reported that shortening the AFC from 3 to 2 years results in a decrease in heifer feed costs of US$21.24 (17.7€), a reduction in production cost of $26.52 (22.1€), and an increase in profit of $25.80 (21.50€) per slaughtered animal per year over the cow's lifetime. Late first calving negatively impacts herd productivity and profitability by decreasing lifetime productivity, increasing management costs, raising replacement rates, and lowering breeding efficiency (Cooke *et al.*, 2013). Therefore, timely first calving is crucial for maintaining profitable and productive cattle production.

The reported AFC for Bali cattle across different management systems is presented in Table 3. Average AFC of 29.32-43.56 months under the intensive management condition (Budisatria *et al.*, 2021; Hidayat *et al.*, 2021), 27.58-43.20 months under semi-intensive management condition (Budisatria *et al.*, 2021; Hidayat *et al.*, 2021), and 26.61-36.76 months under extensive management condition (Hidayat *et al.*, 2021; Prasetya *et al.*, 2022) was reported. These values were comparable to other indigenous cattle in Indonesia, such as Madura cattle (32.70 months) from Pasuruan regency, East Java province (Hartati *et al.*, 2021) and Ongole grade cattle from North Minahasa regency, North Sulawesi province (38.16 months) (Sumiyanti *et al.*, 2023).

**Table 3** The age at first calving (months) of Bali indigenous cattle under varying management conditions across Indonesia

| Management Condition | Study Area | Age at First Calving (Months) | References |
|---|---|---|---|
| Intensive | Jembrana regency, Bali province | 35.32 | (Siswanto *et al.*, 2013) |
| Intensive | South Konawe regency, Southeast Sulawesi province | 43.56 | (Budisatria *et al.*, 2021) |
| Intensive | Badung regency, Bali province | 31.48 | (Wimbavitrati *et al.*, 2020) |
| Intensive | Bungo regency, Jambi province | 33.39 | (Sari *et al.*, 2021) |
| Intensive | Central Bangka regency, Bangka Belitung Islands province | 29.32 | (Hidayat *et al.*, 2021) |
| Extensive | East Halmahera regency, North Maluku province | 37.30 | (Halimah *et al.*, 2022) |
| Semi-intensive | Musi Banyuasin regency, South Sumatra province | 31.93 | (Abidin *et al.*, 2023) |
| Semi-intensive | Bima regency, West Nusa Tenggara province | 33.97 | (Sumadiasa *et al.*, 2024) |
| Semi-intensive | South Konawe regency, Southeast Sulawesi province | 43.20 | (Budisatria *et al.*, 2021) |
| Semi-intensive | Bungo regency, Jambi province | 31.52 | (Sari *et al.*, 2021) |
| Semi-intensive | Central Bangka regency, Bangka Belitung Islands province | 27.58 | (Hidayat *et al.*, 2021) |
| Extensive | Bima and Dompu regency, West Nusa Tenggara province | 36.76 | (Prasetya *et al.*, 2022) |
| Extensive | Bima regency, West Nusa Tenggara province | 35.88 | (Sumadiasa *et al.*, 2024) |
| Extensive | Bungo regency, Jambi province | 34.46 | (Sari *et al.*, 2021) |
| Extensive | Central Bangka regency, Bangka Belitung Islands province | 26.61 | (Hidayat *et al.*, 2021) |
| Pasture agroecosystem | Timor Island, East Nusa Tenggara province | 34.80 | (Habaora *et al.*, 2019) |
| Plantation agroecosystem | Timor Island, East Nusa Tenggara province | 33.60 | (Habaora *et al.*, 2019) |
| Agriculture agroecosystem | Timor Island, East Nusa Tenggara province | 36.00 | (Habaora *et al.*, 2019) |
| Forest agroecosystem | Timor Island, East Nusa Tenggara province | 34.80 | (Habaora *et al.*, 2019) |

In general, the available literature indicated that all recorded values exceeded the normal range for early calving (20 to 27 months of age) (López-Paredes *et al.*, 2018). The AFC is genetically associated with growth and reproduction, both of which are significantly influenced by nutrition, genetics, and management practices (Bach, 2018). The prolonged AFC indicated a lack of awareness among farmers regarding the costs of infertility or a lack of the skills and knowledge necessary to manage the condition. Enhanced management strategies can effectively reduce these periods, leading to improved production and increased profitability for the herd. For instance, Lohakare *et al.* (2012) suggested that providing high-energy or high-concentrate diets may lower the age of sexual maturity, thus decreasing the time to first calving. Genetic selection is another viable approach for modifying AFC, as optimal AFC can differ among individuals. With appropriate genetic selection, it may be possible to reduce the age of sexual maturity and AFC for Bali heifers to as low as 2 years. Ultimately, a combination of genetic selection for AFC and suitable nutritional strategies will facilitate management practices that optimize the overall economic efficiency of beef production.

***Calving interval:*** The CI serves as a key criterion for assessing reproductive performance, particularly in the smallholder beef cattle sector (Bareki *et al.*, 2024). CI is defined as the duration between two consecutive successful births, indicating the reproductive potential of an individual cow (Bene *et al.*, 2022). The ideal CI is theoretically around 365 days (1 year), based on an average gestation period of 283-285 days and days open of 80-82 days. It is not uncommon to observe a CI of less than 365 days, depending on the breed and breeding system employed (Bareki *et al.*, 2024). Given that the length of the CI directly impacts the number of calves produced annually, efforts should concentrate on minimizing the non-productive period to prevent economic losses (López-Paredes *et al.*, 2018).

Table 4 presents the reported CI for Bali cattle. Under intensive management conditions, the shortest CI was recorded as 11.52 months for Bali cattle raised in Jembrana regency, Bali province (Siswanto *et al.*, 2013), while the longest CI was 14.65 months for those raised in South Konawe regency, Southeast Sulawesi province (Budisatria *et al.*, 2021). Conversely, under extensive management conditions, the shortest CI was noted as 11.17 months for Bali cattle in East Halmahera regency, North Maluku province (Halimah *et al.*, 2022), compared to 14.49 months for those raised in Bima regency, West Nusa Tenggara province (Sumadiasa *et al.*, 2024). For semi-intensive management conditions, the lowest CI was reported for Bali cattle in Bungo regency, Jambi province, at 12.33 months (Sari *et al.*, 2021) and the highest value was found in South Konawe regency, Southeast Sulawesi province, at 15.11 months (Budisatria *et al.*, 2021). These CI values for Bali cattle were relatively close to other indigenous cattle in Indonesia, such as Ongole grade cattle from North Minahasa regency, North Sulawesi province (16.00 months) (Sumiyanti *et al.*, 2023), Aceh cattle from North Aceh regency, Aceh province (15.09 months) (Budisatria *et al.*, 2019), and Pasundan cattle from West Java province (14.00 months) (Setiawati *et al.*, 2018).

The values reported for Bali cattle suggested that maintaining a mean CI of 12 months is challenging under all management conditions (Supriyantono *et al.*, 2008; Gunawan *et al.*, 2020; Pian *et al.*, 2020; Budisatria *et al.*, 2021; Prasetya *et al.*, 2022; Sumadiasa *et al.*, 2024). Several factors may contribute to the poor reproductive performance of Bali cattle, including reproductive disorders, management practices, nutrition, and genetic influences (Pribadi *et al.*, 2015). Twomey and Cromie (2023) reported a significant relationship between the interaction of AFC and the parity of the dam concerning CI. They found that the CI for parity 1 cows is considerably longer than that for parity 2, 3, 4, and 5, regardless of AFC. Specifically, for cows with an AFC of 22 to 24 months, the CI is 6 days longer for parity 1 compared to parity 2, and parity 1 cows has a 8-day longer interval than parity 3, 4, and 5 (Twomey and Cromie, 2023).

**Table 4** The calving intervals (months) of Bali indigenous cattle under varying management conditions across Indonesia

| Management Condition | Location | Calving Intervals (Months) | References |
|---|---|---|---|
| Intensive | Jembrana regency, Bali province | 11.52 | (Siswanto *et al.*, 2013) |
| Intensive | Timor Tengah Utara regency, East Nusa Tenggara province | 12.51 | (Nubatonis and Dethan, 2021) |
| Intensive | South Konawe regency, Southeast Sulawesi province | 14.65 | (Budisatria *et al.*, 2021) |
| Intensive | Karang Asem regency, Bali province | 12.53 | (Supriyantono *et al.*, 2008) |
| Intensive | Tabanan regency, Bali province | 13.34 | (Supriyantono *et al.*, 2008) |
| Intensive | Bungo regency, Jambi province | 12.46 | (Sari *et al.*, 2021) |
| Intensive | Central Bangka regency, Bangka Belitung Islands province | 13.63 | (Hidayat *et al.*, 2021) |
| Semi-intensive | Musi Banyuasin regency, South Sumatra province | 12.56 | (Abidin *et al.*, 2023) |
| Semi-intensive | Bima regency, West Nusa Tenggara | 13.76 | (Sumadiasa *et al.*, 2024) |
| Semi-intensive | South Konawe regency, Southeast Sulawesi province | 15.11 | (Budisatria *et al.*, 2021) |
| Semi-intensive | Kupang regency, East Nusa Tenggara province | 13.08 | (Pian *et al.*, 2020) |
| Semi-intensive | Bungo regency, Jambi province | 12.33 | (Sari *et al.*, 2021) |
| Semi-intensive | Central Bangka regency, Bangka Belitung Islands province | 13.06 | (Hidayat *et al.*, 2021) |
| Extensive | East Halmahera regency, North Maluku province | 11.17 | (Halimah *et al.*, 2022) |
| Extensive | Bima and Dompu regency, West Nusa Tenggara province | 13.71 | (Prasetya *et al.*, 2022) |
| Extensive | Bima regency, West Nusa Tenggara province | 14.49 | (Sumadiasa *et al.*, 2024) |
| Extensive | Bungo regency, Jambi province | 13.07 | (Sari *et al.*, 2021) |
| Extensive | Central Bangka regency, Bangka Belitung Islands province | 12.70 | (Hidayat *et al.*, 2021) |
| Lowlands with an altitude of <300 m above sea level | Polewali Mandar regency, West Sulawesi province | 12.04 | (Muslimiah *et al.*, 2023) |
| Highlands with an altitude of >300 m above sea level | Polewali Mandar regency, West Sulawesi province | 11.74 | (Muslimiah *et al.*, 2023) |
| Crop-livestock system | Tegal regency, Central Java province | 13.56 | (Gunawan *et al.*, 2020) |
| Livestock-forestry system | Tegal regency, Central Java province | 13.82 | (Gunawan *et al.*, 2020) |
| Crop-livestock-forestry system | Tegal regency, Central Java province | 12.38 | (Gunawan *et al.*, 2020) |
| Lowland | West Nusa Tenggara province | 11.93 | (Pribadi *et al.*, 2015) |
| Highland | West Nusa Tenggara province | 12.16 | (Pribadi *et al.*, 2015) |

A prolonged postpartum anestrus can extend the CI. This extended anestrus significantly hinders reproductive efficiency in cattle, making it difficult to achieve an average CI of 12 months. Research indicated that malnutrition is a contributing factor to prolonged postpartum estrus, particularly in cows reliant on roughage for their nutritional needs (Randel, 1990; Montiel and Ahuja, 2005; Izquierdo *et al.*, 2021). Additionally, malnutrition interacts with genetic, environmental, and management factors, influencing the timing of estrus (Montiel and Ahuja, 2005). Cows with a low body condition score (BCS) tend to experience longer CI, higher incidence of calving difficulties (Randall *et al.*, 2015), and produce lighter, slower-growing calves compared to those from cows maintaining a BCS of ≥3 (Roche *et al.*, 2009). Consequently, proper nutrition during the breeding period is vital for cows, as it ensures that cows can maintain their health while gaining weight. Supplying appropriate nutrients is vital for overall health, promoting earlier estrus onset and displaying more noticeable signs of heat. While health, nutrition, and husbandry challenges in rural smallholder production systems contribute to reproductive losses, these issues can be effectively addressed through knowledge workshops and training.

***Days open:*** Days open in beef cattle refers to the number of days between calving and conception, significantly impacting fertility and productivity in cattle production. This period is critical for cattle producers as it directly influences reproductive efficiency and herd profitability (Goyache *et al.*, 2005). Generally, a shorter DO period improved reproductive performance, allowing cows to return to estrus promptly after calving (De Vries and Marcondes, 2020). Heifers that become pregnant earlier in the breeding season will calve earlier in the calving season and have a longer interval to rebreeding (Cushman *et al.*, 2013), which is associated with optimal market conditions for calf sales. Conversely, a longer DO can result in economic losses due to higher feed costs and fewer weaned calves per cow annually (Dalcq *et al.*, 2018). Various factors can affect the length of DO in beef cattle. Management practices and breeding decisions play a crucial role in improving conception rates or reducing DO in cows (Temesgen *et al.*, 2022). In addition, nutrition, BCS during transition or at service, season, parity, disease, and heat stress significantly influence the length of DO (Bahonar *et al.*, 2009; Boonkum *et al.* 2011; Jalata *et al.*, 2023; Desta, 2024).

The DO for Bali cattle under varying management conditions are summarized in Table 5. Average DO (days) of 94.80-130.24 (Supriyantono *et al.*, 2008; Sari *et al.*, 2021) under the intensive management condition, 90.10-112.50 under semi-intensive management condition (Pian *et al.*, 2020; Sari *et al.*, 2021), and 69.35-112.40 under extensive management condition (Sari *et al.*, 2021; Halimah *et al.*, 2022) was reported for Bali cattle. The difference may be associated with agroecological conditions where the Bali cattle are raised, which affect the availability and types of feeds. For instance, Bali cattle under a pasture agroecosystem had a shorter DO (292 days) compared to those in a forest agroecosystem (365 days), with the former being raised in a mixed crop-livestock system and the later in semi-arid areas (Habaora *et al.*, 2019).

**Table 5** The days open (days) of Bali indigenous cattle under varying management conditions across Indonesia

| Management Condition | Study Area | Days Open (Days) | References |
|---|---|---|---|
| Intensive | Karang Asem regency, Bali province | 106.00 | (Supriyantono *et al.*, 2008) |
| Intensive | Tabanan regency, Bali province | 130.24 | (Supriyantono *et al.*, 2008) |
| Intensive | Bungo regency, Jambi province | 94.80 | (Sari *et al.*, 2021) |
| Semi-intensive | Musi Banyuasin regency, South Sumatra province | 111.90 | (Abidin *et al.*, 2023) |
| Semi-intensive | Bima regency, West Nusa Tenggara | 108.02 | (Sumadiasa *et al.*, 2024) |
| Semi-intensive | Kupang regency, East Nusa Tenggara province | 112.50 | (Pian *et al.*, 2020) |
| Semi-intensive | Bungo regency, Jambi province | 90.10 | (Sari *et al.*, 2021) |
| Extensive | East Halmahera regency, North Maluku province | 69.35 | (Halimah *et al.*, 2022) |
| Extensive | Bungo regency, Jambi province | 112.40 | (Sari *et al.*, 2021) |
| Extensive | Bima regency, West Nusa Tenggara province | 110.73 | (Sumadiasa *et al.*, 2024) |
| Lowland | West Nusa Tenggara province | 81.00 | (Pribadi *et al.*, 2015) |
| Highland | West Nusa Tenggara province | 88.00 | (Pribadi *et al.*, 2015) |
| Pasture agroecosystem | Timor Island, East Nusa Tenggara province | 292.00 | (Habaora *et al.*, 2019) |
| Plantation agroecosystem | Timor Island, East Nusa Tenggara province | 328.50 | (Habaora *et al.*, 2019) |
| Agriculture agroecosystem | Timor Island, East Nusa Tenggara province | 401.50 | (Habaora *et al.*, 2019) |
| Forest agroecosystem | Timor Island, East Nusa Tenggara province | 365.00 | (Habaora *et al.*, 2019) |

DO has been extensively studied in dairy cattle; however, there is a limited number of studies focused on beef cattle worldwide. The DO reported for Bali cattle is shorter than that of smallholder beef cattle herds in South Africa (DO = 334 days; Nkadimeng *et al.*, 2022), but relatively longer than that of Asturiana de los Valles cattle raised under traditional conditions in the mountainous regions of northern Spain (DO = 103.20 days; Goyache *et al.*, 2005). Various factors influence the length of DO, including genetics, nutrition, and management practices (Keshipour *et al.*, 2024). Inadequate nutrition can prolong DO due to delayed estrus cycles. Disrupted intake and impaired energy metabolism can result in increased levels of circulating ketone bodies. Research has shown that cows with elevated circulating ketone body concentrations experienced more days to first service, decreased first service conception rates, and longer DO (Amin, 2014).

***Number of services per conception:*** The NSC refers to the number of services (natural or artificial insemination) required for conception (Shiferaw *et al.*, 2003). Various studies have reported different fertility parameters for cows, with the CI and NSC being the most prevalent. NSC is a straightforward and commonly used measure to assess fertility and evaluate costs (Khan *et al.*, 2015). It is affected by both genetic and non-genetic factors. Research indicated that season and BCS significantly impact NSC in cows (Jordan, 2003; Nguyen-Kien *et al.*, 2017; Stefanska *et al.*, 2024). A decline in BCS during insemination is a primary risk factor for poor performance (Nguyen-Kien *et al.*, 2017). Meanwhile, the increasing level of temperature-humidity index (THI), particularly in summer, is associated with a higher NSC (Stefanska *et al.*, 2024). This is because the increase in THI above 72 can cause heat stress, which can lead to reduced duration and intensity of estrus, altered follicular development, and impaired embryonic development (Jordan, 2003). Management practices such as accurate estrus detection, bull availability, timing of insemination, proper insemination techniques, semen quality, appropriate semen handling, and pregnancy diagnosis techniques also affect the NSC (Shiferaw *et al.*, 2003).

The ranges of NSC in Bali indigenous cattle under various management conditions are presented in Table 6. In general, the lowest NSC (1.00) was reported for Bali cattle raised under the semi-intensive management condition in Polewali Mandar regency, West Sulawesi province (Dzulqarnain *et al.*, 2024), while the highest NSC (2.70) was reported for Bali cattle under the extensive management conditions in Bungo regency, Jambi province (Sari *et al.*, 2021). The recorded values were far better than those reported for Ongole cross from Indonesia (NSC, ranging from 1.28 to 4.15) (Salman *et al.*, 2021). Other studies reported relatively similar range values, including in Madura cattle raised under smallholder farmers (NSC, ranging from 1.48 to 1.73) (Zuhri *et al.*, 2019), in Aceh cattle under the intensive management condition (NSC = 1.13) (Bakhtiar *et al.*, 2015), and in Pasundan cattle under the extensive management condition (NSC, ranging from 1.40 to 1.60) (Sumaryadi *et al.*, 2021).

The NSC higher than 2 should be regarded as poor (Dinka, 2012). Therefore, all recorded values indicated good reproductive performance of Bali cattle (Supriyantono *et al.*, 2008, Gunawan *et al.*, 2020, Budisatria *et al.*, 2021, Saputra *et al.*, 2022, Dzulqarnain *et al.*, 2024), although some studies have reported NSC levels exceeding 2 (Sari *et al.*, 2021). The variation in NSC may be influenced by several factors, including environmental conditions, bull fertility, the quality of artificial insemination (AI) techniques, reproductive health, estrus detection, parity, breed, and the season of AI (Nubatonis and Dethan, 2021; Tadesse *et al.*, 2022; Mwangi *et al.*, 2023). Management practices adopted at the farm level such as regular estrus detection, AI protocols, and timely veterinary interventions can significantly enhance reproductive performance (Mwangi *et al.*, 2023). For example, the use of estrus detection aids and synchronization protocols, such as timed AI programs, has been shown to reduce NSC by ensuring that insemination occurs close to ovulation (Dalton *et al.*, 2005).

Research indicated that utilizing high-quality semen, in conjunction with optimal timing concerning the cow's estrus cycle, can enhance CR (Martini *et al.*, 2022). A study by Miles *et al.* (2023) demonstrated that bulls selected for their fertility exhibited a considerably lower NSC than their counterparts, suggesting the significance of genetic selection. Additionally, the farmers' knowledge regarding cattle management may impact NSC levels. To achieve optimal reproductive performance and reduce economic losses, beef cattle farmers should regularly monitor their cows and receive training to identify cows in estrus. AI technicians should also be trained to provide accurate AI services, while the government should play an active role in improving local breeds.

***Conception rate:*** A cow's lifetime productivity begins with the onset of puberty and is influenced by subsequent critical events, including AFC, length of the postpartum interval after successive calvings, CR, and pregnancy rate, which ultimately affect the duration of CI (Diskin and Kenny, 2016). The CR, defined as the percentage of females that become pregnancy at a given insemination, serves as an indicator of female fertility. Cow productivity is closely associated with two primary factors: weaning weight and the percentage of calves weaned (Burns *et al.*, 2010). Since CR impacts the percentage of cows that wean calves, low CR can significantly decrease overall herd productivity.

The CR for Bali cattle under varying management systems are presented in Table 7. Overall, the CR varied from 33.70% in the agricultural agroecosystem (Habaora *et al.*, 2019) to 83.00% in the crop-livestock-forestry production system (Gunawan *et al.*, 2020). As reported by Deskayanti *et al.* (2019), Bali cattle raised under the intensive management condition in West Sumbawa regency, West Nusa Tenggara province have CR 60%, but this increases to 77-83% when managed under forestry-livestock, crop-livestock, or crop-livestock-forestry management conditions (Gunawan *et al.*, 2020).

**Table 6** The number of services per conception (NSC) of Bali indigenous cattle under varying management conditions across Indonesia

| Management Condition | Study Area | Number of Services per Conception | References |
|---|---|---|---|
| Intensive | Jembrana regency, Bali province | 1.66 | (Siswanto *et al.*, 2013) |
| Intensive | Badung regency, Bali province | 1.30 | (Saputra *et al.*, 2022) |
| Intensive | Timor Tengah Utara regency, East Nusa Tenggara province | 1.45 | (Nubatonis and Dethan, 2021) |
| Intensive | South Konawe regency, Southeast Sulawesi province | 1.00 | (Budisatria *et al.*, 2021) |
| Intensive | Karang Asem regency, Bali province | 1.23 | (Supriyantono *et al.*, 2008) |
| Intensive | Tabanan regency, Bali province | 1.02 | (Supriyantono *et al.*, 2008) |
| Intensive | Bungo regency, Jambi province | 1.90 | (Sari *et al.*, 2021) |
| Intensive | Central Bangka regency, Bangka Belitung Islands province | 1.62 | (Hidayat *et al.*, 2021) |
| Intensive | Sumbawa Barat regency, West Nusa Tenggara province | 1.70 | (Deskayanti *et al.*, 2019) |
| Semi-intensive | South Konawe regency, Southeast Sulawesi province | 1.20 | (Budisatria *et al.*, 2021) |
| Semi-intensive | Tianggea subdistrict, South Konawe regency, Southeast Sulawesi province | 1.00 | (Dzulqarnain *et al.*, 2024) |
| Semi-intensive | Palangga subdistrict, South Konawe regency, Southeast Sulawesi province | 1.00 | (Dzulqarnain *et al.*, 2024) |
| Semi-intensive | Baito subdistrict, South Konawe regency, Southeast Sulawesi province | 1.30 | (Dzulqarnain *et al.*, 2024) |
| Semi-intensive | Buke subdistrict, South Konawe regency, Southeast Sulawesi province | 1.00 | (Dzulqarnain *et al.*, 2024) |
| Semi-intensive | Central Bangka regency, Bangka Belitung Islands province | 1.38 | (Hidayat *et al.*, 2021) |
| Semi-intensive | Bungo regency, Jambi province | 1.70 | (Sari *et al.*, 2021) |
| Extensive | Central Bangka regency, Bangka Belitung Islands province | 1.25 | (Hidayat *et al.*, 2021) |
| Extensive | Bungo regency, Jambi province | 2.70 | (Sari *et al.*, 2021) |
| Extensive | East Halmahera regency, North Maluku province | 1.20 | (Halimah *et al.*, 2022) |
| Lowlands with an altitude of <300 m above sea level | Polewali Mandar regency, West Sulawesi province | 1.26 | (Muslimiah *et al.*, 2023) |
| Highlands with an altitude of >300 m above sea level | Polewali Mandar regency, West Sulawesi province | 1.30 | (Muslimiah *et al.*, 2023) |
| Extensive | Bima and Dompu regency, West Nusa Tenggara province | 1.59 | (Prasetya *et al.*, 2022) |
| Crop-livestock system | Tegal regency, Central Java province | 1.37 | (Gunawan *et al.*, 2020) |
| Livestock-forestry system | Tegal regency, Central Java province | 1.40 | (Gunawan *et al.*, 2020) |
| Crop-livestock-forestry system | Tegal regency, Central Java province | 1.26 | (Gunawan *et al.*, 2020) |

**Table 7** The conception rate (%) of Bali indigenous cattle under varying management conditions across Indonesia

| Management Condition | Study Area | Conception Rate (%) | References |
|---|---|---|---|
| Intensive | Timor Tengah Utara regency, East Nusa Tenggara province | 70.59 | (Nubatonis and Dethan, 2021) |
| Intensive | West Sumbawa regency, West Nusa Tenggara province | 60.00 | (Deskayanti *et al.*, 2019) |
| Lowlands with an altitude of <300 m above sea level | Polewali Mandar regency, West Sulawesi province | 79.43 | (Muslimiah *et al.*, 2023) |
| Highlands with an altitude of >300 m above sea level | Polewali Mandar regency, West Sulawesi province | 77.00 | (Muslimiah *et al.*, 2023) |
| Crop-livestock system | Tegal regency, Central Java province | 79.00 | (Gunawan *et al.*, 2020) |
| Livestock-forestry system | Tegal regency, Central Java province | 77.00 | (Gunawan *et al.*, 2020) |
| Crop-livestock-forestry system | Tegal regency, Central Java province | 83.00 | (Gunawan *et al.*, 2020) |
| Pasture agroecosystem | Timor Island, East Nusa Tenggara province | 50.30 | (Habaora *et al.*, 2019) |
| Plantation agroecosystem | Timor Island, East Nusa Tenggara province | 53.40 | (Habaora *et al.*, 2019) |
| Agriculture agroecosystem | Timor Island, East Nusa Tenggara province | 33.70 | (Habaora *et al.*, 2019) |
| Forest agroecosystem | Timor Island, East Nusa Tenggara province | 56.00 | (Habaora *et al.*, 2019) |

Overall, CR in beef cattle is influenced by various factors, including genetic and non-genetic components. Significant effects on CR have been attributed to sire line and mating system; different CR among sires (16.5% vs. 36.8%) was reported by Luz *et al.* (2018). AI programs' success depends on the quality of the semen used, and higher CR can be obtained when utilizing sires with strong fertility during the breeding season (Luz *et al.*, 2018). Additional factors affecting CR in beef cattle include heat stress, age or parity, peripartum disorders, and BCS (Quintela *et al.*, 2004; Nabenishi *et al.*, 2018; Kim and Jeong, 2019). The weather in tropical countries like Indonesia may cause heat stress in beef cattle. Heat stress has been reported to decrease CR in Japanese Black cattle (Nabenishi *et al.*, 2018). When heifers or cows experience heat stress, their reproductive efficiency declines, resulting in reduced duration and intensity of estrus, altered follicular development, and impaired embryonic development.

Age has been reported to affect CR in African cattle, with a notable 98% of conceptions occurring in cows aged 4–10 years, while lower rates are observed in those below 4 years and above 10 years (Samkange *et al.*, 2019). This pattern may be attributed to the immature reproductive tracts of younger animals and the senescence of older animals (Moorad and Nussey, 2016). Cows experiencing peri- or postpartum disorders have a lower probability of CR (Kim and Jeong, 2019). Research indicated that peri- and postpartum disorders, such as retained placenta, metritis, and dystocia can adversely affect CR (Quintela *et al.*, 2004). Meanwhile, higher BCS before calving and at first service, along with reduced BCS loss in the first month after calving, are positively correlated with increased CR (Tillard *et al.*, 2008). To improve the CR in Bali cattle and improve animal production efficiency, nutritional, environmental, and management strategies aimed at preventing heat stress during the fertilization period and reducing the incidence of disease is necessary.

***Gestation length:*** The GL is the interval between conception and subsequent parturition (Norman *et al.*, 2009). It can significantly influence farm productivity by delaying subsequent calvings throughout a cow's lifespan (Ahmed *et al.*, 2024). The average GL for beef cattle is generally 280-283 days, or approximately 9 months (Mitchell *et al.*, 2024). Understanding this timeframe is essential for producers, as it directly affects calving schedules, herd size, and overall profitability. Effective management of GL is crucial for planning calving seasons. A well-timed calving season enables producers to optimize resources, manage labor effectively, and enhance the health of both calves and cows. The main objective of commercial cow-calf operations is to optimize pounds of calf produced per cow as economically as possible.

Table 8 presents the GL of Bali cattle raised under various management conditions. The GL ranged from 275.58 days (Wimbavitrati *et al.*, 2020) to 292.91 days (Suranjaya *et al.*, 2019). As reported by Sumadiasa *et al.* (2024), the GL of Bali cattle raised under the semi-intensive management condition in Bima regency, West Nusa Tenggara province was 277.81 days, but it increased to 285.28 days when raised under the extensive management condition. On Timor Island, East Nusa Tenggara province, Bali cattle exhibited varying GL depending on the agroecosystem, with 279.83 days observed in the forest agroecosystem, 282.88 days in the pasture agroecosystem, 285.92 days in the plantation agroecosystem, and 288.96 days in the agricultural agroecosystem (Habaora *et al.*, 2019).
The reported values indicated that the GL of Bali cattle varies 0across different management conditions and locations. The GL can influence the health, productivity, and fertility of the offspring. It is a complex phenotype affected by both genetic and non-genetic factors. Research has shown that progesterone

levels, prenatal growth, maternal age, and maternal and fetal immune systems significantly impact GL (Norman *et al*., 2009; Fang *et al*., 2019). Using a Bayesian fine-mapping analysis, Fang *et al.* (2019) identified 25 candidate genes related to GL, with ZNF613 emerging as a promising candidate gene for this trait. Previous studies have reported moderate to high heritability of GL in Bali cattle (Gunawan *et al*., 2013; Galuh *et al*., 2014), indicating that it is feasible to modify GL through genetic selection.

**Table 8** The gestation length (days) of Bali indigenous cattle under varying management conditions across Indonesia

| Management Condition | Study Area | Gestation Length (Days) | References |
|---|---|---|---|
| Intensive | South Konawe regency, Southeast Sulawesi province | 277.71 | (Budisatria *et al*., 2021) |
| Intensive | Badung regency, Bali province | 284.63 | (Saputra *et al*., 2022) |
| Intensive | Badung regency, Bali province | 275.58 | (Wimbavitrati *et al*., 2020) |
| Intensive | Timor Tengah Utara regency, East Nusa Tenggara province | 279.00 | (Nubatonis and Dethan, 2021) |
| Semi-intensive | Bima regency, West Nusa Tenggara | 277.81 | (Sumadiasa *et al*., 2024) |
| Semi-intensive | South Konawe regency, Southeast Sulawesi province | 278.92 | (Budisatria *et al*., 2021) |
| Extensive | Bima and Dompu regency, West Nusa Tenggara | 276.79 | (Prasetya *et al*., 2022) |
| Extensive | Bima regency, West Nusa Tenggara | 285.28 | (Sumadiasa *et al*., 2024) |
| Pasture agroecosystem | Timor Island, East Nusa Tenggara province | 282.88 | (Habaora *et al*., 2019) |
| Plantation agroecosystem | Timor Island, East Nusa Tenggara province | 285.92 | (Habaora *et al*., 2019) |
| Agriculture agroecosystem | Timor Island, East Nusa Tenggara province | 288.96 | (Habaora *et al*., 2019) |
| Forest agroecosystem | Timor Island, East Nusa Tenggara province | 279.83 | (Habaora *et al*., 2019) |

Fetal development in cattle is closely related to GL, which influences the calf's birth weight. The gestational period is categorized into three trimesters: first trimester (40–99 days), second trimester (100–199 days), and third trimester (200–280 days) after AI (Maeda *et al*., 2024). Major fetal growth occurs during the third trimester (O'Rourke *et al*., 1991), affecting the GL. Any disturbances in this phase, including nutritional deficiencies or health problems, can either prolong or shorten the gestation period. Larger fetuses may require extended gestation times for proper growth, increasing the risk of mortality close to birth (Johanson and Berger, 2003). Therefore, from a management standpoint, understanding the expected calving date (i.e., conception date plus GL) is essential for making informed nutritional decisions, scheduling health assessments, and determining dry-off dates to ensure optimal cow welfare without hindering post-calving performance.

In conclusion, this review highlighted a range of reproductive performances in Bali cattle under varying management conditions. The present review also identified key reproductive traits that require attention, specifically AFC and CI. While environmental factors significantly influence most reproductive traits, this study indicated considerable variation in reproductive characteristics across different management conditions and populations. Consequently, management interventions and selection schemes may enhance reproductive performance. Additionally, most Bali cattle are raised by smallholder farmers who face challenges such as poor animal identification and lack of knowledge, leading to significant data loss as reproductive activities cannot be reliably attributed to specific animals. A fundamental step towards improvement in farm level is the assignment of individual animal identification followed by thorough performance records. Accurate recording is essential for enhancing livestock production, and smallholder farmers could greatly benefit from implementing systematic performance recording. Furthermore, livestock keepers should regularly monitor cows and receive training on reproductive management. Policymakers should invest in education and training for farmers, offering workshops and seminars to equip them with knowledge about reproductive technologies, estrus detection, and AI practices. This comprehensive approach will ultimately lead to improved productivity and reproductivity, thereby increasing economic benefits for farmers. Future research in genetics, nutrition, tropical environmental management, and reproductive technology will be pivotal in improving reproductive performance in Bali cattle.

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