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Research Article

Production Characteristics and Reproductive Performance of Indonesia Kerinci Buffaloes Based on Different Agroecosystems

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Abstract | Swamp buffaloes (*Bubalus bubalis*) are economically important in rural Indonesia, yet populations have declined; in Kerinci Regency, numbers fell from 3.811 in 2022 to 1.533 in 2023, highlighting the need for conservation strategies. This study characterized morphometric and reproductive performance of Kerinci swamp buffaloes across three agroecosystems (rice fields, hills, and swamp). Using purposive sampling in three villages, 626 buffaloes (173 males, 454 females) owned by 52 farmers were assessed. Reproductive traits were obtained via questionnaires, while seven linear body measurements were taken; morphometric indices were calculated and agroecosystem effects tested using generalized linear models, with principal component analysis (PCA) applied to summarize phenotypic variation (P<0.05). Morphometry differed by age, sex, and agroecosystem, with swamp environments producing larger dimensions, particularly in calves where swamp reared animals showed greater body measurements than those from rice fields and hills. In adults, differences varied; adult males in swamp had greater vertical dimensions and CsG, whereas rice field males showed greater CsD. Indices suggested agroecosystem-linked conformation: HSI was negative in swamp but positive in rice fields and hills; DI was highest in rice fields, while FLI was highest in swamp. PCA showed PC1 (85.1%) captured overall body size with positive correlations among traits, with CsD contributing most to differentiation. Sexual maturity and first estrus were uniform (32–33 months), while hills showed later first mating and calving; swamp had earliest first calving (42.77±11.12 months), shortest postpartum intervals (return to estrus 2.88±0.51 months; remating 2.92±0.49 months), and most efficient calving interval (15.15±0.99 months), with gestation12 months. The findings indicate that swamp agroecosystems support superior growth and postpartum reproductive efficiency in tropical highland environments.

Keywords | Agroecosystems, Buffalo population, Kerinci buffaloes, Livestock development, Morphometric, Reproductive performance

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INTRODUCTION

Swamp buffalo *(Bubalus bubalis)* is a ruminant livestock species that plays a significant economic and cultural role in rural Indonesian communities. Its ability to thrive in challenging environmental conditions and utilize low-quality feed renders it a strategic commodity for the development of sustainable livestock farming (Pehan *et al.*, 2025). However, buffaloes receive comparatively less attention than other livestock, such as chickens and cattle, as evidenced by the decline in national and regional buffalo populations. Malewa *et al*. (2025) reported a 15% decrease in population between 2015 and 2022 in almost all regions of Indonesia, while Prihandini *et al*. (2023) noted a sharp decline of 39.35% between 2002 and 2017, placing Indonesia third after Sri Lanka and Thailand in terms of buffalo population decline. This situation necessitates well-directed strategic efforts to sustainably increase the buffalo population.

A deep understanding of the morphometric and reproductive characteristics of buffalo is crucial for livestock development. Morphometry provides key indicators regarding adaptive potential, production capacity, and genetic uniqueness, which are important for breeding and conservation programs (Malewa *et al*., 2025). Buffalo reproductive performance is influenced by intrinsic and extrinsic factors, including variability in environmental conditions such as temperature, rainfall patterns, and feed quality across different agroecosystems (Hendrawan *et al*., 2025). Buffalo exhibit more complex reproductive challenges than cattle, including less obvious estrus signs, seasonal infertility, postpartum anestrus, long calving intervals, and delayed puberty. Consequently, morphometric and reproductive characterization of buffalo in various agroecosystems is highly important for scientific development and practical applications. From a conservation perspective, this research provides baseline data for the management of genetic resources and the identification of populations with unique adaptive traits worthy of preservation (Agung *et al*., 2018). In the context of breeding, this study enables the identification of superior genotypes capable of adapting to specific environmental conditions and serves as the basis for selection strategies to improve productivity (Saputra *et al*., 2020). Furthermore, this research contributes to the understanding of livestock resilience mechanisms and the development of adaptation strategies to cope with climate change (Pehan *et al*., 2025).

Kerinci Regency, located in Jambi Province, is a highland area surrounded by the Bukit Barisan mountain range and encompasses various agroecosystems in the buffer zone of Kerinci Seblat National Park (TNKS). Buffaloes hold significant economic and cultural importance for the local community. The buffalo farming system in this region remains largely traditional, with small-scale farmers managing their livestock using semi-intensive or extensive methods; buffaloes are typically grazed during the day and housed at night in simple wooden and bamboo sheds with earthen floors. Three primary grazing agroecosystems exist: rice fields, hillsides, and swamp lands at the foot of Mount Kerinci, each exhibiting distinct grazing characteristics. Nevertheless, the buffalo population in Kerinci Regency has experienced a substantial decline. Data from the Central Statistics Agency of Kerinci Regency indicate a sharp decrease in 2023, with only 1.533 head remaining a reduction of over 50% compared to 3.811 head in 2022 (BPS, 2024). This situation necessitates a well structured development strategy for buffalo husbandry, grounded in a comprehensive, agroecosystem-based study to ensure the effective development of swamp buffaloes. Currently, scientific information regarding the production and reproductive characteristics of swamp buffaloes within smallholder livestock systems, based on agroecosystem variations, is limited, highlighting the essential need for further research to support sustainable development.

Previous studies have reported on Kuntu buffalo (Yendraliza *et al*., 2021), West Aceh (Rahmatullah *et al*., 2024), Central Java (Johari *et al*., 2009), Moa Island (Pipiana *et al*., 2012), Napu (Malewa *et al*., 2025), Kalimantan (Suhardi *et al*., 2022), and Banten (Murni *et al*., 2020). However, to the best of our knowledge, information regarding the morphometric and reproductive characteristics of swamp buffaloes in the tropical highlands of Kerinci is currently lacking, particularly concerning variations in their agroecosystem management. This study aims to analyze the morphometry and reproductive performance of swamp buffaloes in Kerinci, a tropical highland region in Indonesia. This research is important for assessing the productivity and reproduction of swamp buffaloes based on their agroecosystem management. The findings of this research are expected to provide valuable baseline data for sustainable development, genetic resource conservation programs, and improvements in swamp buffalo productivity in Indonesia and similar tropical environments, aligning with agroecosystem suitability. This study represents the first evaluation of production and reproductive characteristics of male and female swamp buffaloes across calf, young, and adult age groups, considering diverse agroecosystem management practices in Kerinci, Indonesia.

MATERIALS AND METHODS

Description of the research location

This study was conducted in Kerinci Regency, Indonesia (Figure 1). This area is located between 01°41' and 02°26' South Latitude and 101°08' and 101°40' East Longitude and is one of the regencies in Jambi Province. The elevation ranges from above 500 to 3.805 m above sea level. The average temperature is 22.90-24.04°C and the average rainfall is 32.40–380.40 mm. The data collection locations included three villages with different buffalo husbandry systems in distinct agroecosystems: Tanjung Tanah Village (rice field Agroecosystem), Ambai Village (Hill Agroecosystem), and Sungai Rumpun Village (Swamp Agroecosystem). A more detailed description of the research location is provided in Table 1.

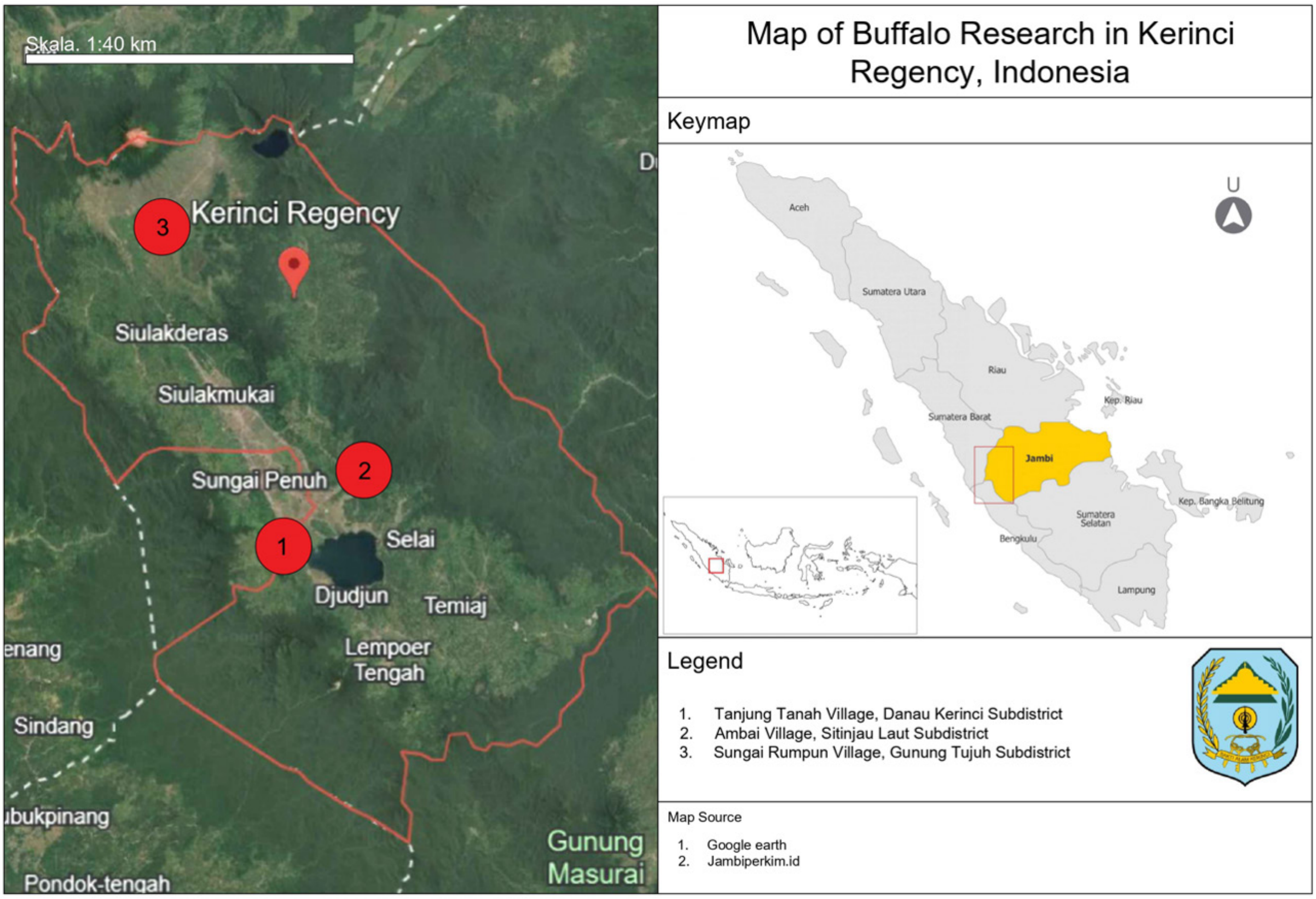

Figure 1: Map of the Kerinci buffalo research location.

Table 1: Description of the research location.

Description	Tanjung Tanah	Ambai	Sungai Rumpun
Average temperature (°C)	30.23	30.39	24.18
Humidity (%)	65.26	65.27	69.12
Wind speed (m/second)	0.57	0.34	2.13
Buffalo population (head)	268	141	217
Rearing management	Semi intensive	Semi intensive	Extensive

Sampling method

To further investigate the reproductive performance and variation in the morphological characteristics of Kerinci buffaloes based on different agroecosystems in the study area, we first consulted with stakeholders in this case, the Department of Animal Husbandry before selecting the research location. We also conducted field assessments to establish a sampling framework, determining from which villages samples would be taken and ensuring the distribution of Kerinci buffaloes in the study sites according to the different maintenance agroecosystems. A purposive sampling method was used for the selection procedure. Tanjung Tanah (n= 268), Ambai (n=141), and Sungai Rumpun (n= 218) Villages were chosen based on differences in agroecosystem maintenance and Kerinci buffalo distribution. These three villages were selected because of the suitability of their maintained agroecosystems, larger populations, and farmers willingness to participate in the research. The analysis of reproductive performance and morphometric traits involved 52 farmers. A total of six hundred twenty-six (627) Kerinci buffaloes, including 173 males and 454 females, were examined in this study. Questionnaires with predetermined questions were prepared to obtain valid and comprehensive information on the reproductive performance of buffaloes. Morphometric measurements were conducted for each buffalo sample.

Data collection

Reproductive performance

Reproductive performance data were collected using a well structured comprehensive questionnaire. Interviews were conducted with the farmers to obtain reproductive data. The variables assessed for reproductive performance included age at sexual maturity, age at first estrus, age at first mating, age at first calving, gestation length, estrus cycle, post-partum estrus, post-partum mating, calving interval, and weaning age.

Morphometric characteristics

Morphometric data were recorded and collected using a standardized format for each specimen. Measurements were conducted in the morning to minimize the influence of feeding and drinking behaviors on body size; animals were positioned standing upright on a flat surface to reduce size variation. Linear measurements of the animals' bodies were performed using a measuring stick and measuring tape. All measurements were carried out by the same researcher to reduce subjective errors during the sampling process. Body measurements are reported in centimeters (cm). The body measurement variables were recorded with precision using a stick and measuring tape, including body length (BdL), chest girth (CsG), chest depth (CsD), chest width (CsW), withers height (WsH), hip height (HpH), and hip width (HpW). The definitions of each measurement are as follows: (1) BdL = the straight line from the bottom of the sacrum to the tip of the ischium bone (os ischium), measured with a measuring stick; (2) CsG = a circular measurement around the body just behind the scapula, measured with a measuring tape; (3) CsD = the distance from the top of the withers to the sternum, measured with a measuring stick; (4) CsW = the width between the protrusions of the left and right shoulder joints (os scapula), measured with a measuring stick; (5) WsH = the vertical distance from behind the scapula to the ground, measured with a measuring stick; (6) HpH = the vertical distance from the sacrum to the ground, measured with a measuring stick; and (7) HpW = the width between the two hip joints, measured with a measuring stick. Animal age was determined through dental observation and analysis of farmer records.

Morphometric indexs

The morphometric index was calculated to assess livestock characteristics based on differences in maintenance agroecosystems using the recommended formula (Alderson, 1999), as summarized in Table 2.

Table 2: Formulas used to analyze the morphometric index.

Type of index	Calculation method
Height Slope (HSI)	Hip Height - Shoulder Height
Width Slope (WSI)	Hip Width - Chest Width
Length Indeks (LI)	Body Length / Shoulder Height
Depth Indeks (DI)	Chest Depth / Shoulder Height
Foreleg length (FLI)	Shoulder Height - Chest Depth

Data analysis

Descriptive analysis was applied to calculate the mean, standard deviation, and morphometric index analysis using Microsoft Office Home 2024 Apps: Excel. Generalized Linear Models (GLM) were used to identify morphometric characteristics based on agroecosystems. Statistical significance was set at $P < 0.05$. Subsequently, Principal Component Analysis (PCA) was applied to reduce the dimensionality of the morphometric data. Data analysis was performed using R (R Core Team, R version 4.3.2).

RESULTS AND DISCUSSION

Morphometric characteristics

The results of the morphometric body measurements of male Kerinci buffaloes are presented in Table 3. In the adult age group, although there were no significant differences ($P>0.05$) between agroecosystems, the morphometric differences observed were relatively variable-specific. Adult buffaloes in the swamp agroecosystem tended to have the highest vertical linear dimensions, with a WsH of 123.50 ± 4.27 cm, HpH of 122.50 ± 3.54 cm, and CsG (181.50 ± 6.16 cm) slightly higher than those in rice fields (116.78 ± 4.49 and 117.21 ± 3.37 cm) and hill (117.33 ± 2.89 and 118.67 ± 5.39 cm). Conversely, adult buffaloes in rice fields showed a greater CsD (71.73 ± 9.06 cm) than those from hill (65.00 ± 4.36 cm) and swamp (59.00 ± 9.80 cm), indicating a relatively better thoracic cavity capacity. Adult buffaloes from hill excelled in HpW (47.00 ± 7.21 cm) and maintained a competitive CsW (40.67 ± 3.21 cm) compared to those from rice fields (43.91 ± 5.30 and 41.31 ± 4.11 cm) and swamp (46.25 ± 2.47 and 42.00 ± 4.24 cm). BdL of adult buffaloes across the three agroecosystems was relatively similar: 118.09 ± 7.52 cm (rice fields), 118.33 ± 1.69 cm (hill), and 116.00 ± 1.41 cm (swamp).

In the young age group, the influence of agroecosystem on morphometrics appeared to be more pronounced. Young buffaloes in hill and swamp generally had greater linear measurements compared to those in rice fields; BdL was 100.79 ± 11.00 cm (rice fields), 110.75 ± 9.98 cm (hill), and 116.50 ± 14.85 cm (swamp), while their respective WsH were 107.43 ± 6.35, 115.50 ± 3.70, and 112.50 ± 6.36 cm. Similarly, CsG was larger in hill (161.75 ± 13.05 cm) and swamp (158.00 ± 1.41 cm) than in race fields (152.57 ± 12.54 cm). Young buffaloes from hill showed greater CsD (60.62 ± 4.71 cm) than those from rice fields (55.93 ± 3.79 cm) and swamp (46.00 ± 1.41 cm), while young buffaloes from swamp had greater CsW (36.00 ± 1.41 cm) than those from rice fields (33.79 ± 5.07 cm) and hill (33.12 ± 2.66 cm). The HpW in young buffaloes ranged from 38.36 ± 4.38 cm (rice fields), 40.50 ± 3.70 cm (hill), to 39.75 ± 0.35 cm (swamp), indicating that the intermediate growth phase is still highly responsive to feed quality and management in each agroecosystem.

The most notable differences were observed in the calf age group, where buffaloes raised in swamp agroecosystems consistently showed the highest values for nearly all morphometric variables. The BdL of swamp buffalo calves reached 100.33 ± 8.50 cm, which was much greater than

Table 3: Morphometric characteristics of male Kerinci Buffalo, Indonesia.

Morpho-metric	Adult			Young			Calves		
	Rice fields	Hill	Swamp	Rice fields	Hill	Swamp	Rice fields	Hill	Swamp
BdL	118,09 ± 7.52	118,33 ± 1.69	116,00 ± 1.41	100.79 ± 11.00	110.75 ± 9.98	116.50 ± 14.85	76.62 ± 15.07[b]	78.00 ± 9.54[b]	100.33 ± 8.50[ab]
CsG	174,06 ± 9.37	178,67 ± 8.08	181,50 ± 6.16	152.57 ± 12.54	161.75 ± 13.05	158.00 ± 1.41	119.50 ± 28.16[b]	126.67 ± 3.51[b]	151.00 ± 3.00[a]
CsD	71,73 ± 9.06	65,00 ± 4.36	59,00 ± 9.80	55.93 ± 3.79[b]	60.62 ± 4.71[b]	46.00 ± 1.41[ab]	41.12 ± 8.43	46.00 ± 5.20	52.33 ± 1.53
CsW	41,31 ± 4.11	40,67 ± 3.21	42,00 ± 4.24	33.79 ± 5.07	33.12 ± 2.66	36.00 ± 1.41	27.12 ± 4.17[b]	25.00 ± 1.00[b]	37.17 ± 2.75[a]
WsH	116,78 ± 4.49	117,33 ± 2.89	123,50 ± 4.27	107.43 ± 6.35	115.50 ± 3.70	112.50 ± 6.36	92.25 ± 12.97	96.33 ± 1.15	110.33 ± 2.52
HpH	117,21 ± 3.37	118,67 ± 5.39	122,50 ± 3.54	106.14 ± 10.99	115.00 ± 7.87	113.00 ± 8.49	92.75 ± 12.69[b]	97.33 ± 2.89[b]	109.00 ± 4.00[a]
HpW	43,91 ± 5.30	47,00 ± 7.21	46,25 ± 2.47	38.36 ± 4.38	40.50 ± 3.70	39.75 ± 0.35	30.88 ± 4.63[b]	28.00 ± 2.00[b]	39.67 ± 1.15[a]

Data are presented as mean ± standard deviation (SD). Different superscript letters in the same row indicate a significant difference ($P<0.05$). body length (BdL); chest girth (CsG); chest depth (CsD); chest width (CsW); withers height (WsH); hip height (HpH); and hip width (HpW).

Table 4: Morphometric characteristics of female Kerinci Buffalo, Indonesia.

Morpho-metric	Adult			Young			Calves		
	Rice fields	Hill	Swamp	Rice fields	Hill	Swamp	Rice fields	Hill	Swamp
BdL	121.55 ± 6.97[b]	124.00 ± 10.49[b]	132.70 ± 6.70[a]	102.00 ± 5.57	105.33 ± 8.96	108.25 ± 14.50	72.25 ± 12.34[b]	73.50 ± 9.19[b]	96.00 ± 5.29[a]
CsG	177.93 ± 11.28	180.00 ± 20.55	191.60 ± 3.13	144.00 ± 9.17	153.00 ± 6.08	162.00 ± 24.11	112.00 ± 14.45[b]	107.00±14.14[b]	144.67 ± 6.11[a]
CsD	72.03 ± 6.21[a]	63.20 ± 6.98[b]	62.10 ± 6.27[b]	55.67 ± 8.08	54.33 ± 1.53	60.25 ± 0.96	40.12 ± 4.33[b]	39.00 ± 5.66[b]	58.33 ± 2.08[a]
CsW	42.37 ± 4.80	44.80 ± 4.97	43.80 ± 3.05	36.00 ± 2.65	29.33 ± 5.51	40.75 ± 5.91	24.00 ± 4.38[b]	23.00 ± 2.83[b]	32.00 ± 2.00[a]
WsH	118.34 ± 4.80	122.00 ± 8.28	123.90 ± 4.72	103.33 ± 5.77[b]	111.67±5.69[ab]	116.00 ± 4.24[a]	84.75 ± 6.70[b]	88.50 ± 9.19[b]	105.67 ± 5.13[a]
HpH	118.40 ± 5.44	122.20 ± 7.05	121.20 ± 4.92	104.00 ± 6.24[b]	110.33±4.93[ab]	118.75 ± 4.03[a]	84.25 ± 8.73[b]	92.00 ± 7.07[b]	108.00 ± 3.46[a]
HpW	45.61 ± 5.86	51.60 ± 3.58	48.50 ± 3.16	36.67 ± 0.58[b]	43.67 ± 4.73[a]	43.88 ± 1.93[a]	28.75 ± 2.06[b]	27.75 ± 8.13[b]	37.33 ± 1.53[a]

Data are presented as mean ± standard deviation (SD). Different superscript letters in the same row indicate a significant difference ($P<0.05$). body length (BdL); chest girth (CsG); chest depth (CsD); chest width (CsW); withers height (WsH); hip height (HpH); and hip width (HpW)

those in rice fields (76.62 ± 15.07 cm) and hill (78.00 ± 9.54 cm); their CsG of 151.00 ± 3.00 cm also surpassed both rice fields (119.50 ± 28.16 cm) and hill (126.67 ± 3.51 cm). Similarly, CsD (52.33 ± 1.53 cm) and CsW (37.17 ± 2.75 cm) were higher in swamp than in rice fields (41.12 ± 8.43 and 27.12 ± 4.17 cm) and hill (46.00 ± 5.20 and 25.00 ± 1.00 cm). The WsH and HpH of swamp calves were 110.33 ± 2.52 and 109.00 ± 4.00 cm, respectively, while those in rice fields were 92.25 ± 12.97 and 92.75 ± 12.69 cm, and in hill 96.33 ± 11.15 and 97.33 ± 2.89 cm, respectively. The HpW of calves in swamp (39.67 ± 1.15 cm) was also larger than that of calves in rice fields (30.88 ± 4.63 cm) and hill (28.00 ± 2.00 cm). Some of the swamp buffalo calves' measurements, such as BdL and CsG, were approaching the values of young buffaloes in rice fields (100.79 ± 11.00 cm and 152.57 ± 12.54 cm), indicating a faster initial growth rate in the swamp environment and underscoring the interaction between age and agroecosystem type.

The results of the morphometric body measurements of female Kerinci buffaloes are presented in Table 4. Morphometric measurements of adult females showed significant differences ($P<0,05$) between agroecosystems for several parameters. The BdL of adult buffaloes in swamp (132.70 ± 6.70) and hill (124.00 ± 10.49) was significantly greater than that in rice fields (121.55 ± 6.97). A similar pattern was observed for CsG, where the highest value was found in swamp (191.60 ± 3.13), followed by hill (180.00 ± 20.55) and rice fields (177.93 ± 11.28), although there was no significant difference. Other parameters, such as CsD, CsW, WsH, HpH, and HpW, also showed the highest values in swamp and hill, with some significant differences observed between rice fields and the other two habitats, as reflected by the different superscripts.

In young females, morphometric parameters showed clearer variation between agroecosystems, with significant differences (P<0,05). BdL of young buffaloes in swamp (108.25 ± 14.50) and hill (105.33 ± 8.96) was greater than that in rice fields (102.00 ± 5.57), although there was no difference in BdL in young buffaloes, but swamp tended to be superior. The CsG of young buffaloes in rice fields (144.00 ± 9.17), hill (153.00 ± 6.08), and swamp (162.00 ± 24.11) also shows that the swamp agroecosystem tends to be superior, although without a significant difference. CsD of young females in rice fields (55.67 ± 8.08), hill (54.33 ± 1.53), and swamp (60.25 ± 0.96) also showed a similar trend. CsW in rice fields (36.00 ± 2.65), hill (29.33 ± 5.51), and swamp (40.75 ± 5.91) indicates larger measurements in the swamp agroecosystem. WsH, HpH, and HpW of young buffaloes showed significant differences between rice fields and other agroecosystems, with rice fields tending to have smaller measurements than swamp and hill.

In female calves, the differences between agroecosystems were clearer and more significant (P<0,05) for several parameters. Calf BdL in swamp (96.00 ± 5.29) was significantly greater than that in rice fields (72.25 ± 12.34) and hill (73.50 ± 9.19). Calf CsG also showed significant differences, with the highest value in swamp (144.67 ± 6.11) and lower values in Rice fields (112.00 ± 14.45) and hill (107.00 ± 14.14). Calf CsD in swamp (58.33 ± 2.08) was significantly greater than that in rice fields (40.12 ± 4.33) and hill (39.00 ± 5.66). Calf CsW in swamp (32.00 ± 2.00) was also higher than that in rice fields (24.00 ± 4.38) and hill (23.00 ± 2.83). WsH, HpH, and HpW in calves showed the same pattern, with significantly higher values in swamp and lower values in rice fields and hill.

The morphometric data of male Kerinci buffaloes (Table 3) show that morphometric differences among agroecosystems tend to be variable-specific, and a similar pattern was observed in female buffaloes (Table 4). Adult male buffaloes in swamp agroecosystems generally have the largest linear dimensions CsG, WsH, and HpH compared to the other two agroecosystems, although these differences are not statistically significant; a similar situation was observed in female buffaloes. These findings are consistent with previous studies (Hendrawan *et al*., 2025; Mohd Azmi *et al*., 2021) that confirmed that morphometric characteristics in livestock are influenced not only by genetic factors but also by specific environmental conditions and livestock management. Kerinci buffaloes in swamp agroecosystems exhibit larger body dimensions than those in rice fields and hill, particularly in CsG, BdL, WsH, and HpH. CsG is a key factor in livestock classification; the larger the thoracic cavity, the more space is available for vital organs, such as the lungs and heart (Masho *et al*., 2022). Animals with a larger CsG typically have higher body weights. The results are consistent with the findings of Hendrawan *et al*. (2025) on highland and lowland buffaloes in Jambi and Rahmatullah *et al*. (2024) on highland and coastal buffaloes in West Aceh. Dudi *et al*. (2012), Murni *et al*. (2020), and Suhardi *et al*. (2020, 2022) affirm that different environmental conditions result in distinct morphometric characteristics in buffaloes. Each agroecosystem produces unique environmental and vegetative conditions. The Kerinci swamp agroecosystem, particularly known as Rawa Bento, is a muddy wetland area rich in forage, offering more supportive conditions than rice fields or hills. This morphometric variation might also indicate phenotypic adaptation to the specific environmental conditions of each agroecosystem, where swamp buffaloes tend to develop larger and taller bodies for optimal mobility in the muddy terrain.

Overall, male Kerinci buffaloes have smaller body frames, specifically CsG, WsH, and HpH, than Kuntu buffaloes. However, the CsG of female Kerinci buffaloes is larger than that of Kuntu buffaloes, as reported by Yendraliza *et al*. (2021), and this is consistent with the findings of Nur *et al*. (2018) for male Jepara buffaloes. The BdL of male Kerinci buffaloes in this study was relatively similar across all maintenance agroecosystems. These findings are smaller than those reported by Komariah *et al*. (2014), Murni *et al*. (2020), Nastiti *et al*. (2023), Nur *et al*. (2018), Rahmatullah *et al*. (2024), Suhardi *et al*. (2020), and Yendraliza *et al*. (2021). In contrast, the female buffaloes in this study had longer BdL than those in the aforementioned studies. CsD differed based on agroecosystem, with buffaloes in rice fields having the highest values, followed by those in hill and swamp. Deeper chest cavities benefit animals by providing a larger pleural cavity that aids lung expansion (Gelaye *et al*., 2022). These results are consistent with the findings of Suhardi *et al*. (2020) on Kalang buffaloes in North and East Kalimantan, but are smaller than those of Kalang buffaloes in South Kalimantan and Thale Noi buffaloes in Phatthalung, Thailand. Conversely, the chest depth values in this study were larger than those of male Napu buffaloes from Central Sulawesi (Malewa *et al*.,2025). The CsW of Kerinci buffaloes aligns with the findings of Hendrawan *et al*. (2025) and Suhardi *et al*. (2022), but is larger than the values reported by Rahmatullah *et al*.

(2024), whereas lower values were noted by De Melo *et al.* (2018). Meanwhile, the HpW of Kerinci buffaloes is wider than that of crossbred Murrah buffaloes (De Melo *et al.*, 2018) but is consistent with that of Kalimantan buffaloes (Suhardi *et al.*, 2022).

Morphometric results in the calves phase showed significant differences (P<0.05) across agroecosystems, with buffaloes in the swaps agroecosystem consistently having larger body sizes in all measured parameters than those in the rice fields and hilly. For example, the BdL of female buffalo calves in swamp (96.00 ± 5.29 cm) was much greater than that in rice fields (72.25 ± 12.34 cm) and hill (73.50 ± 9.19 cm). This pattern was also observed for CsG, CsD, CsW, WsH, HpH, and HpW, where the values for wetlands were always higher and significantly so compared to the other two agroecosystems. These differences underscore the evident influence of agroecosystems on morphometry, particularly during the early growth phase. Furthermore, these findings suggest that the morphometric traits of Kerinci buffaloes during the early growth stages may be greatly influenced by the agroecosystem, including soil conditions, forage availability, and topography, which shape specific morphological adaptations in each environment. These adaptations are the result of complex genetic and environmental integration, where genes associated with digestive metabolism, physical strength, and milk production undergo selection, contributing to the morphometric differences between swamp buffaloes and river buffaloes (Luo *et al.*, 2020; Zhang *et al.*, 2020). Additionally, swamp rich in resources, such as fertile soils, abundant water, and high-quality forage, permit optimal growth and morphological development, enhancing the morphometric advantages of buffalo calves. Selective pressures in these environments promote adaptive responses that improve developmental performance from early life stages, thus establishing a strong correlation between swamp agroecology and the phenotypic expression of local buffalo morphometry, as observed in Kerinci buffaloes (Pineda *et al.* 2021). Therefore, the superior morphometry of Kerinci buffalo calves in swamp agroecosystems is a biological manifestation of genetic interactions and environmental adaptation that optimizes growth and survival in swamp habitats. These morphological adaptations are a clear example of how environmental pressures shape distinct and advantageous phenotypic expressions in the context of swasps agroecosystems (Luo *et al.*, 2020; Macciotta *et al.*, 2021; Pineda *et al.*, 2021).

Morphometric indices

The morphometric indices of Kerinci buffaloes are presented in Tables 5 and 6. The HSI showed a contrasting pattern between agroecosystems, where male buffaloes in swamp displayed a negative value (-1.00), while male buffaloes in rice field and hilly agroecosystems showed positive HSI values (0.44) and (1.33), respectively. A similar condition was also observed in female buffaloes, where the HSI in swamp was negative and tended to be more extreme (-2.70). The highest WSI value for males was found in buffaloes from the hilly agroecosystem (6.33), followed by swamp (4.25) and rice fields (2.60). For females, the pattern was almost the same, with the highest WSI in the hilly agroecosystem, followed by swamp and rice fields. The LI values of Kerinci buffaloes, both male and female, from all agroecosystems showed similar values (1), with only a slightly lower value among swamp males (0.94). The DI values for males and females also revealed a similar pattern, with the rice field agroecosystem being the highest (0.61) for both males and females, followed by hills and swamp. Conversely, the highest FLI value was found in the swamp agroecosystem for both males and females, with values of (64.50) and (61.80), respectively, followed by hills, and the lowest in rice fields.

Table 5: Morphometric Indices of Male Kerinci Buffalo, Indonesia.

Parameter	Male		
	Paddy fields	Hilly areas	Swamps
HSI	0,44 ± 1.74	1,33 ± 5.51	-1,00 ± 2.83
WSI	2,60 ± 6.36	6,33 ± 6.66	4,25 ± 1.77
LI	1,01 ± 0.04	1,01 ± 0.12	0,94 ± 0.06
DI	0,61 ± 0.07	0,55 ± 0.03	0,47 ± 0.14
FLI	45,05 ± 8.08	52,33 ± 4.16	64,50 ± 3.44

Height Slope (HSI); Width Slope (WSI); Length Indeks (LI); Depth Indeks (DI); and Foreleg length (FLI).

Table 6: Morphometric indices of female Kerinci Buffalo, Indonesia.

Parameter	Female		
	Paddy fields	Hilly areas	Swamps
HSI	0,05 ± 2.26	0,20 ± 3.96	-2,70 ± 2.91
WSI	3,25 ± 4.96	6,80 ± 2.59	4,70 ± 2.22
LI	1,03 ± 0.06	1,02 ± 0.06	1,07 ± 0.04
DI	0,61 ± 0.04	0,52 ± 0.03	0,50 ± 0.06
FLI	46,31 ± 5.21	58,80 ± 4.32	61,80 ± 8.53

Height Slope (HSI); Width Slope (WSI); Length Indeks (LI); Depth Indeks (DI); and Foreleg length (FLI).

Morphometric indices, including height slope index (HSI), width slope index (WSI), length index (LI), depth index (DI), and foreleg length index (FLI), were analyzed. Morphometric indices are the correlations between linear body measurements used to define the proportions and size of an animal, obtained through the measurement of linear body size (Gelaye *et al.*, 2022). The results of this study indicate that there are differences in the morphometric indices of male Kerinci buffalo (Table 5) raised in three different agroecosystems (rice field, hill, and swamp). The

HSI showed a contrasting pattern between agroecosystems, where male buffalo in swamp exhibited negative values, whereas those in rice fields and hilly agroecosystems showed positive HSI values. This difference indicates that male buffaloes in swamp have shoulders that are higher than their hips, whereas buffaloes in hill are the opposite. Moreover, a negative HSI value can illustrate a backline that tends to slope backward, whereas a positive HSI value closer to zero in buffalo in rice fields indicates a flatter backline. A more level back profile in male buffaloes in rice fields might be an adaptive advantage for movement in rice fields that require stability on soft soil. Conversely, a negative HSI value in male buffalo in swamp may facilitate movement on steep muddy wetlands with higher forelegs, although this still requires further research. Several other studies on ruminant livestock (Suhardi *et al*., 2020) have summarized that positive HSI values are also found in Kalang buffalo in Kalimantan and Thale Noi buffalo in Phatthalung, Thailand. Positive HSI values have also been reported for buffaloes in South Sulawesi (Rusdin *et al*., 2022). Negative HSI values have also been observed in local Indonesian cattle (Adinata *et al*., 2023). The WSI values of male Kerinci buffalo from all agroecosystems were positive, indicating that male Kerinci buffalo have a wider hip width than chest width. This finding is consistent with that of Rusdin *et al*. (2022) in the buffalo population in Southeast Sulawesi, where a positive WSI value indicates that local Sulawesi buffalo belong to the broad-bodied type. This result is also in line with the observations of Gelaye *et al*. (2022) and Masho *et al*. (2022) on local cattle in Southwest Ethiopia.

The LI value of one (1.00) for male Kerinci buffalo in rice fields and hill indicates an ideal body proportion, with body length nearly equal to height, a characteristic associated with balanced growth and good body structure. Conversely, male swamp buffaloes with a lower LI (0.94) have a more compact body structure. This result is consistent with the report by Suhardi *et al*. (2020) that male Kalang buffalo in North Kalimantan have an HSI value of (0.96), while in East Kalimantan, it is (1.00). Similar findings were also reported by Rusdin *et al*. (2022) for buffaloes in Southeast Sulawesi. The LI value can vary depending on the management system and environment in which the animals are raised (Alderson, 1999). Differences in agroecosystems have different environmental and topographic characteristics, with swamp being muddy and wet, whereas hills have an undulating terrain. Additionally, different agroecosystems provide different feed availability and quality. Differences in nutritional support capacity between habitats can lead to variations in body size and conformation (Dudi *et al*., 2012; Murni *et al*., 2020). The DI values for male Kerinci buffalo differed, with the highest values in rice fields agroecosystems, followed by hill and swamp. Higher DI values indicate a larger chest capacity. This is in line with the report (Suhardi *et al*., 2020) on buffaloes in Kalimantan Island. Gelaye *et al*. (2022) also noted differences in DI values among male cattle in Southwest Ethiopia, where cattle in district DB had better DI values than those in GB. The chest depth (DI) index is crucial for fitness and a healthy respiratory system, especially in cattle accustomed to high altitudes (Gelaye *et al*., 2022). The FLI value also differed, with swamp male buffalo having the highest value, followed by hill, and the lowest in rice fields. Higher values indicate legs that are proportionally longer than the chest depth, a characteristic that can influence movement across different topographies of agroecosystems. These findings suggest that male buffalo in swamp may exhibit morphological specialization for swamp environments with longer front legs, facilitating movement in deep water and muddy conditions.

The morphometric indices of female Kerinci buffaloes are presented in Table 4. The HSI values in female Kerinci buffalo showed a similar pattern, where buffalo in swamp had negative HSI values, while rice fields and hill had positive values. This finding indicates that female buffaloes in swamp have higher shoulders than hips, whereas buffaloes in rice fields and hill are the opposite. These results are lower than those reported by Suhardi *et al*. (2020) for female Kalang and Thale Noi buffalo in Phatthalung, Thailand, and Masho *et al*. (2022) for local female cattle in Southwest Ethiopia. Conversely, the WSI values were higher than those reported by Suhardi *et al*. (2020). However, they are consistent with the findings of Rusdin *et al*. (2022) on buffaloes in Southeast Sulawesi and Gelaye *et al*. (2022) on local cattle in Ethiopia. The LI in female Kerinci buffalo was relatively similar across all agroecosystems. This result is consistent with previous findings (Rusdin *et al*., 2022; Suhardi *et al*., 2020). Warman *et al*. (2023) reported similar findings for female Bali cattle. Conversely, these results are lower than those of local female cattle in Ethiopia (Gelaye *et al*., 2022; Masho *et al*., 2022). The highest DI in female Kerinci buffalo was observed in rice paddies, followed by hills and swamp. Conversely, the highest FLI in females was in swamp, followed by hills, and the lowest in rice fields. These results indicate that female buffalo in rice fields have higher body characteristics with wider hips. Thus, the morphometric index results indicate that female buffalo have adapted to the environment. Overall, the findings of this study show that male and female Kerinci buffalo, which have been raised for generations and are ingrained in the community with a close cultural connection, may have adapted to maintaining the agroecosystem environment.

Principal component analysis

Principal Component Analysis (PCA) of the morphometric data of Kerinci buffalo (Figure 2) demonstrated that the first two principal components summarized the majority of the phenotypic diversity within the population. PC1 accounted for 85.1% of the total variance, whereas PC2 explained 5.2%; therefore, the biological interpretation mainly focused on the PC1 axis. In the correlation circle, all observed traits CsD, CsG, CsW, WsH, BdL, HpH, and HpW are strongly projected towards the positive direction of PC1 and tend to align with each other, indicating a strong positive correlation among variables and the integration of body size. The relatively long vector lengths and their proximity to the correlation circle suggest that these traits are well represented in the PC1-PC2 plane, making this two dimensional space sufficiently representative for summarizing the main patterns of covariation in the data. This pattern confirms that PC1 can be viewed as the overall body size dimension, whereas PC2 adds minor variation information related to relative proportions.

The interpretation of the variable contributions shows that thoracic traits play a dominant role in forming the PCA space. Among all variables, CsD made the most prominent contribution to the first two components, indicating that variation in thoracic depth is the main explainer of morphometric differentiation in this population. Other variables such as CsG, followed by linear body measurements such as BdL, WsH, and HpH, are also strongly associated with the positive direction of PC1, reinforcing the interpretation of PC1 as a gradient of overall body size increase. The second principal component (PC2) was relatively minor and did not exhibit significant opposing changes among the primary variables. Given its limited contribution, PC2 is more appropriately interpreted as a secondary variation that captures subtle differences in proportion after the general size effect has been accounted for by the first principal component (PC1).

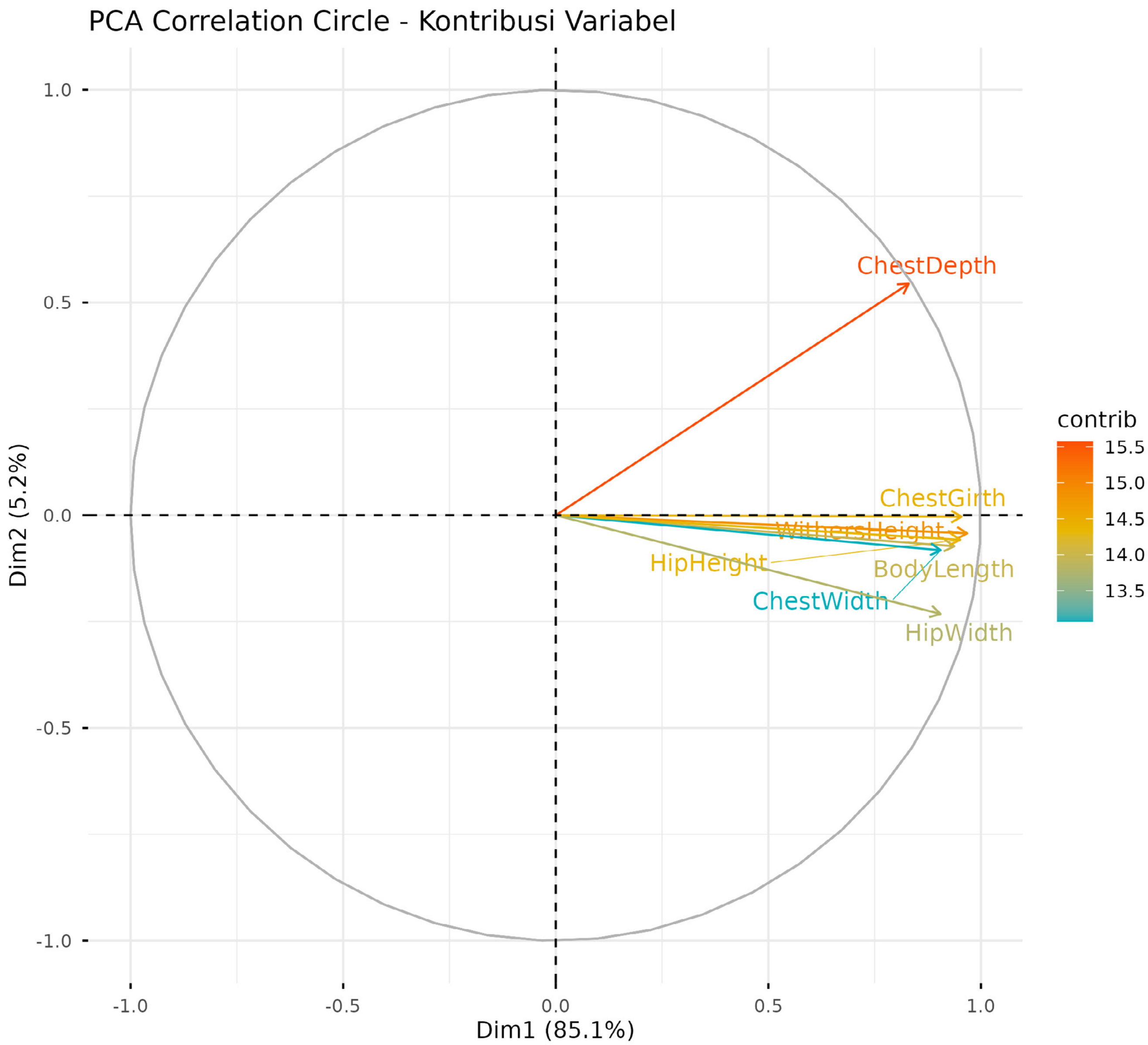

Figure 2: PCA correlation circle (Pearson), PC1- PC2.

Principal Component Analysis (PCA) of the morphometric characteristics of Kerinci buffalo (Figure 2) showed that the first two principal components captured most of the phenotypic variation. In the PC1-PC2 plane, PC1 explained 85.1% of the total variance, and PC2 explained 5.2%, indicating that the main pattern of variation in the population was primarily projected onto the first axis. Other studies have reported that three principal components in highland buffaloes explain 74.16%, and two principal components in lowland buffaloes explain 69.45% of the variation (Hendrawan *et al.*, 2025). Dahiya *et al.* (2021) reported four principal components explaining 59.52% of the total variation in Murrah buffaloes. Raut *et al.* (2023) identified five principal components that accounted for 61.90% of the total variation in Marathwadi buffalo.

The high contribution of thoracic traits in Kerinci buffalo, as revealed by the PCA results, especially in CsW and CsG, indicates that variation in the chest region is a key component distinguishing individuals in this population. The size of the thorax in buffaloes is conceptually closely related to thoracic cavity capacity, which indicates the animal's potential physiological capacity. Thoracic characteristics are important predictors of livestock phenotypic assessment, particularly in terms of production and adaptability to the environment. Thoracic size not only reflects physical aspects but also the capacity of vital physiological functions in buffalo and is often used as an important phenotypic parameter in livestock selection and management to improve productivity and environmental adaptation (Zhang *et al.*, 2020). PC1 represents the general body size, and shifts in PC1 scores across agroecosystems can be interpreted as reflecting differences in environmental conditions and management affecting the accumulated growth of Kerinci buffalo. However, the continued overlap between agroecosystem groups indicates that the effect of the agroecosystem does not form completely separate morphotypes but rather shifts the mean within a single population spectrum. The agroecosystem effect alters phenotypes through phenotypic plasticity and local genetic adaptation, allowing livestock populations to display continuous variation within the same population spectrum in response to heterogeneous environments and management practices. This confirms that the morphotypes formed are not separate categories but rather the result of a phenotypic distribution pattern, with means that shift according to agroecosystem conditions (Aboul-Naga *et al.*, 2022; Kebede *et al.*, 2021; Mashamaite and Tada, 2025; Mustefa *et al.*, 2024).

Reproductive characteristics

The reproductive characteristics were evaluated and are summarized in Table 7. The age at sexual maturity and age at first estrus were relatively uniform across all agroecosystems, each ranging between 32 and 33 months. Buffaloes in the hilly agroecosystem showed the latest age at first mating (34.71 ± 5.39 months) and age at first calving (48.00 ± 4.71 months) compared to those in Rice fields (32.40 ± 6.73 months and 44.00 ± 6.69 months, respectively) and wetlands (32.77 ± 5.26 months and 42.77 ± 11.12 months, respectively). Gestation length was relatively similar in all three agroecosystems, ranging from 11.96 to 12.00 months. The estrous cycle in the hilly agroecosystem (29.00 ± 0.76 days) was the longest compared to that in Rice fields (27.80 ± 3.90 days) and was the shortest in wetlands (25.88 ± 5.36 days). Meanwhile, postpartum performance in the wetland agroecosystem, such as the interval to return to estrus after calving (2.88 ± 0.51 months), interval to remating after calving (2.92 ± 0.49 months), and calving interval (15.15 ± 0.99 months), was the most efficient compared to the Rice field and hilly agroecosystems. The weaning age was relatively uniform (9.1–9.4 months) across all three agroecosystems in this study.

Table 7: Reproductive Characteristics of Kerinci Buffalo, Indonesia.

Parameter	Agroecosystems		
	Paddy fields	Hilly areas	Swamps
Age at sexual maturity (Months)	32.27 ± 6.66	32.57 ± 6.95	32.77 ± 5.26
Age at first estrus (Months)	32.40 ± 6.73	33.00 ± 6.11	32.77 ± 5.26
Age at first mating (Months)	32.40 ± 6.73	34.71 ± 5.39	32.77 ± 5.26
Age at first calving (Months)	44.00 ± 6.69	48.00 ± 4.71	42.77 ± 1.12
Gestation length (Months)	12 ± 0.00	12 ± 0.00	11.96 ± 0.14
Estrus cycle (days)	27.80 ± 3.90	29.00 ± 0.76	25.88 ± 5.36
Post-partum estrus (Months)	3.53 ± 0.83	3.40 ± 1.24	2.88 ± 0.51
Post-partum mating (Months)	3.60 ± 0.99	3.47 ± 1.19	2.92 ± 0.49
Calving interval (Months)	15.47 ± 0.92	15. 60 ± 1.06	15.15 ± 0.99
Weaning age (Months)	9.10 ± 1.29	9.43 ± 0.79	9.43 ± 0.53

The reproductive characteristics, such as age at sexual maturity, age at first estrus, age at first mating, age at first calving, gestation length, estrus cycle, post-partum estrus, post-partum mating, calving interval, and weaning age of Kerinci buffalo from three different agroecosystems are summarized in (Table 7). Based on the results of this study, the age at sexual maturity and age at first estrus in Kerinci buffalo were relatively uniform across all agroecosystems, each ranging between (32 and 33 months). Similar findings were reported by Rashid *et al.* (2019), who showed no significant differences in age at sexual maturity among local, crossbred, Nilli, and Murrah buffaloes in Bangladesh (34.41 ± 2.02, 34.74 ± 1.81, 34.12 ± 1.65, and 34.53 ± 1.96 months, respectively). The age at first mating of Kerinci buffaloes in the Rice field and swamp agroecosystems was relatively the same (32 months), while it was highest in the hill agroecosystem (34.71 5.39 months). Pipiana *et al.* (2012) recorded that female buffaloes on Moa Island were first mated at an average age of (31.33±6.16 months). Inadequate feed supply and deficiency of essential nutrients during the growth period are the main causes of delayed puberty (Rashid *et al.*, 2019). Heinrichs *et al.* (2005) added that balanced feeding and better management can support optimal growth and accelerate sexual maturity.

The age at first calving in Kerinci buffalo showed the most significant differences among agroecosystems, with the swamp agroecosystem being the most favorable, where the age at first calving was (42.77 ± 11.12 months). This was followed by the rice field agroecosystem (44.00 ± 6.69 months), while buffaloes in the hill agroecosystem had the oldest age at first calving (48.00 ± 4.71 months). These findings indicate that agroecosystems are correlated with age at first calving. The swamp agroecosystem, characterized by wet conditions, is rich in diverse forage vegetation. This supports the availability of sufficient feed for optimal buffalo reproduction. Inadequate feed can lead to a higher age at first calving and reduced productivity (Garg *et al.*, 2016; Palczynski *et al.*, 2020). A longer age at first calving affects the reproductive efficiency. Providing optimal feeding from pregnancy to weaning can accelerate sexual maturity and lower the age at first calving (Garg *et al.*, 2016). Various other studies have reported (Rashid *et al.*, 2019) that the age at first calving for local, crossbred, Nilli, and Murrah buffaloes in Bangladesh are (46.12 ± 1.66, 46.56 ± 1.64, 46.18 ± 0.88, and 46.25 ± 1.81 months), respectively. Meanwhile, the age at first calving for Kuntu buffaloes (54 ± 1.7 months) (Yendraliza *et al.*, 2021) is higher than that of Kerinci buffaloes. The age at first calving for Brazilian buffaloes (41.67 months) (Marques *et al.*, 2020) is relatively similar to that of the Kerinci buffaloes. Fitriani *et al.* (2023) also recorded the age at first calving for buffaloes in Boyolali (3.60 ± 0.3 years) within the same range as that of Kerinci buffaloes. Differences in the age at first calving can be influenced by differences in management and feeding practices (Rusdin *et al.*, 2020).

The gestation length of Kerinci buffalo was relatively similar across the three agroecosystems, ranging from (11.96–12.00 months). This is longer than the average gestation period for local, crossbred, Nilli, and Murrah buffaloes, which are (312.15 ± 12.04, 313.40 ± 4.97, 313.65 ± 5.16, and 311.59 ± 6.17 days), respectively (Rashid *et al.*, 2019). Similar results were also reported by Rahmatullah *et al.* (2024), with the gestation length of buffaloes in West Aceh Regency being (10.48 ± 0.50 months) in coastal plains and (10.44 ± 0.50 months) in highlands. Likewise, the gestation period for Kuntu buffaloes was (10.5 ± 11.2 months) (Yendraliza *et al.*, 2021). The longer gestation period in Kerinci buffaloes may be due to genetic differences and variations in nutritional management in each region (Rashid *et al.*, 2019). The duration to return to estrus and remate after calving for Kerinci buffalo in the swamp agroecosystem was the shortest (2.88 ± 0.51; 2.92 ± 0.49 months) compared to those in Rice fields and hills, with averages of (3.40 ± 1.24–3.60 ± 0.99 months). These results indicate that different agroecosystems affect postpartum reproduction. The swamp agroecosystem, with optimal water availability and abundant forage, helps improve reproductive efficiency and quicker post-partum recovery (Khan *et al.*, 2020; Perera, 2011). The interval to remating after calving for Kerinci buffalo is shorter than that for Kuntu buffalo (6 ± 5.7 months) (Yendraliza *et al.* 2021).

The calving interval for Kerinci buffalo is relatively similar across all agroecosystems (15.15 ± 0.99–15.60 ± 1.06 months), and is lower than that reported by Rashid *et al.* (2019), who reported average calving intervals of (19.36 ± 2.39 months) for local buffalo, (19.37 ± 2.63 months) for crossbreeds, (19.41 ± 1.66 months) for Nilli Ravi, and (18.31 ± 1.97 months) for Murrah buffalo. Likewise, Habib *et al.* (2023) recorded an average calving interval of 478 days for buffaloes in northern Bangladesh. Rahmatullah *et al.* (2024) reported average calving intervals for buffaloes in West Aceh as (18.28 ± 2.22 months) in coastal plains, while in highlands it is (17.90 ± 2.13 months). Research by Rianto *et al.* (2025) on buffaloes in Central Java also reported a calving interval of 19 months. The shorter calving interval of Kerinci buffaloes is related to a higher postpartum reproductive efficiency. The weaning age of Kerinci buffalo is relatively the same across all agroecosystems (9.10 ± 1.29–9.43 ± 0.53 months) and lower than that of Kuntu buffalo (1 ± 2.2 years) (Yendraliza *et al.*, 2021). Weaning age can affect both the reproductive performance of the dam and the performance of the calf (de la Cruz-Cruz *et al.*, 2020; Vaz and Lobato, 2010).

CONCLUSION

This study demonstrated that Kerinci swamp buffaloes exhibit significant morphometric and reproductive variations influenced by the agroecosystem type. Buffaloes raised in swamp environments show superior growth characteristics, especially in calves, and enhanced reproductive efficiency, including earlier first calving, shorter postpartum intervals, and more efficient calving intervals, compared to those raised in rice fields and hill. These findings highlight the swamp agroecosystem as the most favorable environment for optimizing both physical development and reproductive performance of swamp buffaloes in tropical highland regions, underscoring the importance of targeted conservation and management strategies tailored to the agroecosystem conditions.

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NOVELTY STATEMENT

This study is the first to comprehensively characterize the morphometric and reproductive performance of Bubalus bubalis in Kerinci Regency, a tropical highland region of Indonesia, across three distinct agroecosystems (rice fields, hills, and swamp), encompassing both male and female animals across calf, young, and adult age groups. Unlike previous studies on Indonesian swamp buffaloes that focused on single agroecosystems or limited age classes, this research reveals that the swamp agroecosystem consistently supports superior growth and postpartum reproductive efficiency, providing novel baseline data critical for evidence-based conservation and sustainable buffalo development strategies in tropical highland environments.

AUTHOR'S CONTRIBUTION

NR, RP, LCENSD, BPP, and WA: designing and planning the research. NR and PAH: field-sample measurements. RP, LCENSD, BPP, and WA: monitored the research process. NR: drafted and wrote the manuscript. RP, LCENSD, BPP, and WA: reviewed and edited the manuscript.. The Manuscript has not been published or submitted to other journals previously.

Ethical statement

This study was approved by the Research Ethics Committee of Andalas University (number: 582/UN.16.2/KEP-FK/2025).

Generative AI and AI assisted technology statement

The authors declare that no generative AI and AI assisted technology was used in the creation of this manuscript.

Conflict of interest

The authors have declared no conflict of interest.

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