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A longitudinal study on the production and reproductive performance of the Toda buffalo under traditional management in the Nilgiris

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Abstract

The Toda buffalo is a unique indigenous buffalo population reared by the Toda tribal community in the Nilgiri hills of Tamil Nadu and is well adapted to the high-altitude ecosystem of the Western Ghats. This study evaluated the production, reproductive and milk composition traits of 150 Toda buffaloes maintained under traditional management in eight Toda Munds or settlements near the Sheep Breeding Research Station, Sandynallah. The mean daily milk yield, peak milk yield, lactation length and lactation yield were 2.65 ± 0.39 kg/day, 3.49 ± 0.24 kg, 192.63 ± 6.87 days and 511.30 ± 76.37 kg, respectively. The average age at first calving and calving interval were 45.26 ± 2.37 months and 16.85 ± 1.99 months. Milk composition analysis ($n = 50$) showed mean fat and solid-not-fat (SNF) contents of $8.57 \pm 0.56\%$ and $9.88 \pm 0.50\%$, respectively. Correlation analysis showed strong positive associations between daily milk yield and lactation yield, and between milk fat and SNF ($p < 0.01$). Lactation length was the only significant predictor of daily milk yield. These findings provide baseline information for the conservation, genetic improvement and sustainable utilisation of Toda buffaloes.

Keywords: Toda buffalo, indigenous buffalo, milk yield, reproductive performance, milk composition, fat percentage, SNF, Nilgiris, Toda tribe, conservation

1. Introduction

India possesses a rich diversity of livestock genetic resources, including several indigenous buffalo breeds that are well adapted to specific agro-climatic conditions. According to Karthickeyan *et al.* (2018) [7], the Toda buffalo possesses unique phenotypic and adaptive characteristics that distinguish it from other buffalo populations in India. The Toda buffalo (*Bubalus bubalis*) is one of India's most unique indigenous buffalo breeds and is exclusively reared by the Toda tribal community inhabiting the upper Nilgiris of Tamil Nadu. The breed is a geographically isolated riverine buffalo that has evolved under the unique ecological conditions of the Nilgiri plateau and is recognized as a distinct indigenous buffalo breed by the National Bureau of Animal Genetic Resources (ICAR-NBAGR) [6], Karnal. The animals are highly adapted to high-altitude grasslands, cold climatic conditions, high rainfall, and extensive grazing systems, making them an important component of the fragile mountain ecosystem (Nivsarkar *et al.*, 2000 and Selvamani *et al.*, 2026) [10, 12]. Livestock biodiversity plays a vital role in ensuring global food security, nutritional sustainability, rural livelihoods, and resilience to climate change. Indigenous livestock breeds possess unique genetic characteristics that enable them to survive and perform under harsh environmental conditions where exotic breeds often fail. These breeds represent valuable reservoirs of adaptive genes for disease resistance, heat tolerance, reproductive fitness, and efficient utilization of low-quality feed resources. The conservation and sustainable utilization of indigenous animal genetic resources have therefore become global priorities, particularly in biodiversity-rich countries such as India (FAO, 2019; FAO, 2023) [3, 4].

India possesses the largest buffalo population in the world, accounting for more than half of the global buffalo population and contributing substantially to national milk production. According to the 20th Livestock Census, India has approximately 109.85 million buffaloes,

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contributing nearly 49% of the country's total milk production (Government of India, 2019) ^[5]. While internationally recognized breeds such as Murrah, Jaffarabadi, Mehsana, Nili-Ravi, Surti and Bhadawari dominate commercial dairy production, several lesser-known indigenous buffalo populations continue to survive under traditional production systems. These indigenous populations possess valuable adaptive traits that warrant conservation and scientific evaluation (DAHD, 2023) ^[2].

Among these, the Toda buffalo is one of the most distinctive indigenous buffalo populations of India. It is exclusively reared by the Toda tribe, one of the Particularly Vulnerable Tribal Groups (PVTGs) inhabiting the upper plateau of the Nilgiri Hills in Tamil Nadu. The breed has evolved over centuries under the unique ecological conditions of the Western Ghats, a globally recognized biodiversity hotspot. The Toda buffalo is deeply interwoven with the religious, cultural, and socio-economic life of the Toda community. Buffaloes are regarded as sacred animals, and several religious ceremonies, festivals, and social customs revolve around buffalo husbandry. Unlike commercial dairy buffaloes, Toda buffaloes are traditionally managed under extensive grazing systems with minimal external inputs, making them highly adapted to the montane grasslands and shola forest ecosystem (Kathiravan *et al.*, 2010) ^[8].

Despite relatively lower milk yield compared with specialized dairy breeds, Toda buffaloes produce milk containing exceptionally high fat and total solids, making it highly suitable for the preparation of traditional dairy products including butter, curd, ghee, and ceremonial foods. The superior nutritional quality of Toda buffalo milk has attracted increasing scientific attention because of its potential value in niche dairy markets and indigenous food systems (Kathiravan *et al.*, 2010; ICAR-NBAGR, 2023) ^[8, 6].

The population of Toda buffaloes has declined considerably during the past few decades because of shrinking grazing lands, habitat fragmentation, changing socio-economic conditions, urbanization, reduced interest among younger tribal generations in traditional livestock farming, indiscriminate crossbreeding in surrounding regions, and increasing pressure on natural resources. Climate change, altered rainfall patterns, invasive plant species, and declining grassland ecosystems have further threatened the sustainability of the breed. Consequently, the Toda buffalo has been recognized as an endangered indigenous buffalo genetic resource requiring urgent conservation and scientific documentation (ICAR-NBAGR, 2023; FAO, 2023) ^[6, 4].

Milk production and reproductive efficiency are among the most important economic traits determining the productivity and sustainability of dairy buffaloes. Daily milk yield, peak milk yield, lactation length, and lactation yield directly influence the profitability of dairy farming, whereas age at first calving and calving interval largely determine lifetime productivity and reproductive efficiency. These traits are influenced by genetic makeup, nutrition, environmental conditions, management practices, parity, season, and physiological status of the animals (Singh *et al.*, 2019 and Sharma *et al.*, 2022) ^[15, 13]. Indigenous buffaloes generally exhibit lower milk yield than improved dairy breeds but compensate through greater adaptability, longer productive life, higher disease resistance, and superior milk composition. Assessment of productive and reproductive traits is essential for evaluating the performance and genetic potential of indigenous livestock populations. Production traits such as daily milk yield, peak milk yield, lactation length, and

lactation yield are important indicators of economic productivity, whereas reproductive parameters including age at first calving and calving interval determine reproductive efficiency and herd sustainability (Thiruvenkadan *et al.*, 2010) ^[16]. Similarly, milk composition traits such as fat and solid-not-fat (SNF) content influence milk quality and market value.

In recent years, the population of Toda buffaloes has declined due to reduction in grazing lands, changes in land-use patterns, urbanization, and decreasing interest in traditional buffalo husbandry among younger generations of the Toda community. The need for conservation of Toda buffaloes has been emphasized by Kathiravan *et al.* (2010) ^[8], who highlighted the declining buffalo population and shrinking grazing resources in the Nilgiri hills. Despite its cultural and genetic importance, limited information is available regarding the productive, reproductive, and milk quality characteristics of Toda buffaloes under field conditions. Comprehensive evaluation of these traits is necessary for designing appropriate breeding, management, and conservation programmes. Therefore, the present study was undertaken to assess the production performance, reproductive efficiency, and milk composition traits of Toda buffaloes maintained by Toda tribal communities in selected Munds of the Nilgiris district of Tamil Nadu and to examine the relationships among these economically important traits.

2. Materials and Methods

2.1 Study Area

The present study was conducted in the Toda tribal settlements (Munds) located in and around the Upper Nilgiris region of Tamil Nadu, India. The study area comprised eight major Toda Munds, namely Muthunadu Mund, Aganadu Mund, Anaikal Mund, Kunthakodu Mund, Gadi Mund, Tharanadu Mund, Puthu Mund, and Nearkasi Mund, situated in the vicinity of the Sheep Breeding Research Station (SBRS), Sandynallah, The Nilgiris District. The region is characterised by montane grasslands and shola ecosystems at an altitude ranging from 1,800 to 2,400 m above mean sea level, providing the traditional habitat for Toda buffaloes.

2.2 Selection of Animals and Data Collection

A total of 150 Toda buffaloes maintained by Toda tribal households across the selected Munds were included in the study. Information was collected through personal interviews with buffalo owners, field observations, and available herd records. Data pertaining to herd structure and productive and reproductive performance were recorded.

2.3 Milk Sample Collection and Analysis

Milk samples were collected from a representative subset of lactating Toda buffaloes maintained under traditional management systems. Fresh milk samples were collected in sterile containers during the morning milking and transported under chilled conditions for laboratory analysis.

Milk composition traits milk fat (%) and solid-not-fat (SNF%), were analysed at the Aavin Nilgiris District Co-operative Milk Producers' Union Ltd. Laboratory, The Nilgiris. Standard dairy analytical procedures routinely adopted by the laboratory were followed for the estimation of milk quality parameters.

2.4 Statistical Analysis

The collected data were compiled, tabulated, and analysed using appropriate statistical procedures. Descriptive statistics

were calculated for all production, reproductive, and milk composition traits using SPSS version 26.

Pearson's correlation coefficients were estimated to determine the relationships among production, reproductive, and milk quality traits. Multiple linear regression analysis was performed to identify factors influencing daily milk yield. Statistical significance was tested at 5% and 1% probability levels.

2.5 The regression model used was

$$DMY = \beta_0 + \beta_1(PMY) + \beta_2(LL) + \beta_3(AFC) + \beta_4(CI) + \beta_5(Fat) + \beta_6(SNF) + \varepsilon$$

Where,

DMY = Daily Milk Yield, PMY = Peak Milk Yield, LL = Lactation Length, AFC = Age at First Calving, CI = Calving

Interval, Fat = Milk Fat Percentage, SNF = Solid-Not-Fat Percentage, β_0 = Intercept, β_1 – β_6 = Regression coefficients, and ε = Random error term.

3. Results and Discussion

3.1 Production Performance

The production traits of the study animals are presented in Table 1. The mean daily milk yield was 2.65 ± 0.39 kg/day, ranging from 1.80 to 3.50 kg/day. The coefficient of variation (14.68%) indicated moderate variability among animals, suggesting the influence of management practices, nutritional status, and genetic differences under field conditions. Indigenous cattle breeds generally exhibit lower milk yield compared to exotic and crossbred cattle but possess superior adaptability to harsh environmental conditions and low-input production systems.

Table 1: Production and reproductive traits of the breed in Tamil Nadu

Trait	N	Mean $\pm$ SD	SE	CV (%)	Min–Max
Daily Milk Yield (kg/day)	150	2.65 ± 0.39	0.03	14.68	1.80 – 3.50
Peak Milk Yield (kg)	150	3.49 ± 0.24	0.02	7.00	3.00 – 4.40
Lactation Length (days)	150	192.63 ± 6.87	0.56	3.57	179 – 210
Lactation Yield (kg)	150	511.30 ± 76.37	6.24	14.93	340.20 – 693.00
Age at First Calving (months)	150	45.26 ± 2.37	0.19	5.24	40 – 51
Calving Interval (months)	150	16.85 ± 1.99	0.16	11.80	13 – 24
Milk Fat (%)	50	8.57 ± 0.56	0.08	6.56	7.40 – 10.40
SNF (%)	50	9.88 ± 0.50	0.07	5.04	8.90 – 11.56

The mean peak milk yield was 3.49 ± 0.24 kg, recorded during the early stage of lactation. The relatively low coefficient of variation (7.00%) indicates uniformity in peak production among animals. Similar observations were reported by Kathiravan *et al.* (2011) ^[9], who noted that indigenous cattle maintained under traditional management systems show relatively stable peak yield characteristics.

The average lactation length was 192.63 ± 6.87 days, ranging from 179 to 210 days. The low coefficient of variation (3.57%) demonstrates remarkable uniformity among animals for this trait. Indigenous buffalo breeds maintained under extensive grazing systems usually exhibit lactation lengths ranging from 180 to 240 days depending on nutritional status and environmental conditions. The lactation length observed in the present study agrees well with earlier reports on Toda buffaloes by Kathiravan *et al.*, (2010) ^[8] and ICAR-NBAGR (2023) ^[6], who described the breed as having a relatively stable lactation period despite seasonal fluctuations in feed availability.

The average lactation milk yield was 511.30 ± 76.37 kg, with values varying from 340.20 to 693.00 kg. The coefficient of variation (14.93%) indicates moderate diversity among animals, suggesting that there is considerable scope for genetic improvement through selective breeding. Lactation yield is influenced by several genetic and non-genetic factors including nutrition, parity, health status, management practices and environmental stress. Ranjan *et al.*, (2012) ^[11] reported that improved nutritional management during lactation significantly enhances milk yield in indigenous buffaloes without compromising their adaptability.

Although the milk yield of the present breed is lower than that of high-yielding buffalo breeds such as Murrah or Nili-Ravi, it is comparable with several indigenous buffalo populations maintained under traditional production systems. The comparatively lower milk production should therefore be viewed in the context of the breed's excellent adaptation, disease resistance, longevity and ability to efficiently utilize poor-quality forage. These characteristics contribute

substantially to sustainable livestock production in fragile hill ecosystems.

3.2 Milk Composition Traits

Milk composition analysis revealed an average milk fat content of $8.57 \pm 0.56\%$, with values ranging from 7.40 to 10.40%. Likewise, the average solid-not-fat (SNF) percentage was $9.88 \pm 0.50\%$, ranging between 8.90 and 11.56%. The relatively low coefficients of variation for fat (6.56%) and SNF (5.04%) indicate remarkable consistency in milk composition among animals.

One of the most distinguishing features of indigenous buffalo milk is its high fat concentration. The milk fat percentage observed in the present study exceeds that reported for many commercial dairy cattle breeds and is comparable to previous reports on Toda buffaloes. Kathiravan *et al.*, (2010) ^[8] reported that Toda buffalo milk is particularly rich in fat and total solids, making it highly suitable for the preparation of traditional dairy products such as butter, ghee, curd and indigenous cheeses. High milk fat also increases market value because milk pricing in many regions is based on fat percentage.

Similarly, the higher SNF content recorded in this study reflects the superior nutritional quality of the milk. Elevated SNF values indicate higher concentrations of proteins, lactose and minerals, thereby enhancing the nutritional value and processing characteristics of the milk. According to FAO (2019) ^[3] and ICAR-NBAGR (2023) ^[6], indigenous buffalo milk possesses excellent processing qualities due to its naturally higher concentrations of fat, protein and total solids compared with cattle milk.

The consistently high fat and SNF values observed in the present investigation further support the conservation value of this indigenous breed. Even though the breed produces relatively lower quantities of milk, its superior milk quality makes it economically valuable for niche dairy markets and traditional dairy product manufacturing.

3.3 Reproductive Performance

The average age at first calving was 45.26 ± 2.37 months, with a range of 40–51 months. The coefficient of variation (5.24%) indicates relatively uniform reproductive maturity among animals. However, the age at first calving is slightly higher than that reported for improved buffalo breeds. Delayed sexual maturity is commonly observed in indigenous buffalo populations maintained under extensive grazing systems, where nutritional limitations and seasonal breeding influence reproductive development. Similar observations have been reported by Nivsarkar *et al.*, (2000) ^[10] and Kathiravan *et al.*, (2010) ^[8] for Toda buffaloes.

The calving interval averaged 16.85 ± 1.99 months, ranging from 13 to 24 months, with moderate variability (11.80%). The calving interval recorded in this study is within the normal range reported for indigenous buffalo breeds. Variation in calving interval is largely influenced by postpartum nutrition, body condition score, reproductive management, disease incidence and estrus detection efficiency. Singh *et al.*, (2019) ^[15] observed that improved nutritional management during the postpartum period significantly reduces calving interval and improves lifetime

productivity in buffaloes.

Although reproductive efficiency is relatively lower than in intensively managed commercial buffalo herds, the reproductive performance observed in the present study demonstrates the remarkable adaptability of the breed to extensive production systems. The animals maintain acceptable fertility despite dependence on natural grazing resources and minimal external inputs. Such reproductive resilience is considered one of the major strengths of indigenous livestock genetic resources.

3.4 Correlation among Production, Reproductive and Milk Composition Traits

The correlation matrix (Table 2) revealed several significant relationships among production, reproductive, and milk composition traits. Daily milk yield showed a very strong positive correlation with lactation yield ($r = 0.954$, $p < 0.01$), indicating that increases in daily milk production directly contribute to higher total lactation yield. This finding agrees with reports by Thiruvengadan *et al.* (2010) ^[16], who identified daily milk yield as a major determinant of overall lactation performance.

Table 2: Correlation matrix among production, reproductive and milk composition traits of the study animals (N = 50)

Trait	Daily Milk Yield	Peak Milk Yield	Lactation Length	Lactation Yield	Milk Fat	SNF	Age at First Calving	Calving Interval
Daily Milk Yield (DMY)	1	0.431**	-0.145	0.954**	-0.029	0.034	0.202	-0.104
Peak Milk Yield (PMY)	0.431**	1	0.199	0.496**	0.000	-0.089	-0.037	0.061
Lactation Length (LL)	-0.145	0.199	1	0.157	0.083	-0.003	0.067	0.056
Lactation Yield (LY)	0.954**	0.496**	0.157	1	-0.001	0.032	0.216	-0.087
Milk Fat (%) (Fat)	-0.029	0.000	0.083	-0.001	1	0.771**	0.145	0.003
SNF (%) (SNF)	0.034	-0.089	-0.003	0.032	0.771**	1	0.202	-0.250*
Age at First Calving (AFC)	0.202	-0.037	0.067	0.216	0.145	0.202	1	-0.235
Calving Interval (CI)	-0.104	0.061	0.056	-0.087	0.003	-0.250*	-0.235	1

Peak milk yield also exhibited a significant positive association with lactation yield ($r = 0.496$, $p < 0.01$) and daily milk yield ($r = 0.431$, $p < 0.01$). These relationships suggest that animals attaining higher peak yields are likely to maintain better production throughout lactation.

Milk fat percentage showed a strong positive correlation with SNF content ($r = 0.771$, $p < 0.01$), indicating a close biological association between milk constituents. This result agrees with the findings of Kathiravan *et al.*, (2010) ^[8], who reported that Toda buffalo milk possesses exceptionally high fat and total solids. Similar positive relationships between fat and SNF have also been described by FAO (2019) ^[3] and ICAR-NBAGR (2023) ^[6] for indigenous buffalo breeds. The strong association suggests that selection for improved milk fat percentage may simultaneously enhance overall milk quality.

Interestingly, calving interval showed a significant negative

correlation with SNF ($r = -0.250$; $p < 0.05$). This finding suggests that prolonged reproductive intervals may be associated with slight reductions in milk quality. Although the biological mechanism remains unclear, nutritional deficiencies affecting reproductive performance may also influence milk composition. Similar associations between reproductive efficiency and milk quality have been reported by Berry *et al.*, (2014) ^[1], who emphasised the importance of balanced nutrition in maintaining both reproductive performance and milk constituents.

3.5 Multiple Linear Regression Analysis

Multiple linear regression analysis was performed to evaluate factors influencing daily milk yield (Table 3). The model explained 46% of the total variation ($R^2 = 0.46$) in daily milk yield, indicating moderate predictive ability.

Table 3: Multiple linear regression analysis of factors influencing daily milk yield (N = 50)

Predictor Variable	Unstandardized Coefficient (B)	Standard Error	Standardized Coefficient (β)	t-value	Significance
Constant	2.73	0.06	—	44.69	0.000
Peak Milk Yield	-0.006	0.006	-0.006	-1.14	0.260
Lactation Length	-0.014	0.000	-0.301	-69.46	0.000**
Age at First Calving	0.001	0.001	0.006	1.26	0.215
Calving Interval	0.001	0.001	0.004	0.82	0.417
Milk Fat (%)	-0.006	0.005	-0.010	-1.39	0.171
SNF (%)	0.006	0.005	0.008	1.13	0.266
Model summary					
R	0.68				
R ²	0.46				
Adjusted R ²	0.40				
Std. Error	0.15				

Note: Lactation Yield was removed to avoid mathematical dependency

Daily Milk Yield = $2.729 - 0.006(\text{PMY}) - 0.014(\text{LL}) + 0.001(\text{AFC}) + 0.001(\text{CI}) - 0.006(\text{Fat}) + 0.006(\text{SNF}) + \varepsilon$

The results indicate that production traits are more closely associated with daily milk yield than reproductive and milk composition traits. The moderate coefficient of determination further suggests that additional factors such as feeding management, genetic background, health status, and environmental conditions may also contribute substantially to milk production.

Among the predictor variables, lactation length emerged as the only highly significant factor ($p < 0.01$) affecting daily milk yield. The negative regression coefficient (-0.014) suggests that animals with longer lactation periods tend to produce slightly lower daily milk yields, possibly due to dilution of production over an extended lactation duration.

Peak milk yield, age at first calving, calving interval, milk fat percentage, and SNF content did not show significant effects ($p > 0.05$) on daily milk yield within the present dataset. Similar observations have been reported by Sharma *et al.*, (2022) ^[13] and Singh *et al.*, (2021) ^[14], who emphasised that multiple regression models are useful tools for predicting milk production but should be interpreted together with environmental and management variables.

4. Conclusion

The present study evaluated the production, reproductive, and milk composition traits of the study animals maintained under field conditions in Tamil Nadu. The animals exhibited moderate milk production performance, with an average daily milk yield of 2.65 kg and a lactation yield of 511.30 kg. The relatively low variation observed in lactation length, milk fat percentage, and SNF content indicates a stable performance for these traits within the population.

Milk quality analysis revealed high fat (8.57%) and SNF (9.88%) contents, highlighting the superior nutritional and processing value of the milk. Reproductive performance was characterized by an average age at first calving of 45.26 months and a calving interval of 16.85 months, reflecting the adaptability of the animals to traditional management systems.

Correlation analysis demonstrated strong positive associations among major production traits, particularly between daily milk yield and lactation yield, suggesting that selection for higher daily milk yield could effectively improve overall productivity. Regression analysis identified lactation length as a significant factor influencing daily milk yield, while other production, reproductive, and milk composition traits showed limited direct effects. The findings indicate that the breed possesses desirable characteristics such as adaptability, reproductive stability, and high-quality milk production. The observed variability in production and reproductive traits provides scope for genetic improvement through selective breeding and better management practices. Conservation and systematic improvement of this valuable indigenous genetic resource will contribute to sustainable livestock production and preservation of native cattle biodiversity in Tamil Nadu.

Conflict of Interest

Not available

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Not available

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