Indian Journal of Ecology (2025) 52(5): 1077-1083
DOI: https://doi.org/10.55362/IJE/2025/4619

Manuscript Number: 4619
NAAS Rating: 5.38

Phenotypic Trends and Evaluation of Economic Traits in Surti Buffaloes under Organized Farm

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Abstract: The study evaluated the effect of non-genetic factors, including age, season, period, and parity, on economic traits in Surti buffaloes. Data from 391 buffaloes under the Network Project on Buffalo Improvement (Surti) at LRS, Vallabhnagar, Udaipur (RAJUVAS, Bikaner), were analysed over a 30-year period (1993–2023), encompassing 868 lactation records. Age had a non-significant effect on TMY, TMY_305, LL, CI, DP, and ADMY_LL but significantly influenced LPY and ADMY_CI. Season significantly affected all economic traits, with the highest production observed during winter (November to February). The period of calving had a significant influence on all economic traits, with the highest performance recorded during the first period (1993–1997). Parity significantly affected LPY and ADMY_LL. A declining trend in economic traits was observed up to the sixth period (2018–2023), indicating a need for improved management strategies to sustain productivity.

Keywords: Economic traits, Non-genetic factors, Surti buffaloes, Phenotypic trend

India, with the world's largest buffalo population, plays a crucial role in milk and meat production, significantly contributing to socio-economic development in both rural and urban areas. Of the 204 million buffaloes worldwide, 97% are in Asia, with India alone hosting 109.85 million, representing 57% of the global population (20th Livestock Census 2019). Buffaloes are the highest milk-producing species in India and have a higher fat percentage compared to cattle, making them more valuable for dairy production. The average daily milk yield of buffaloes in India (6.9 kg/animal) is higher than that of indigenous cattle (3.9 kg/animal), reinforcing their economic importance in the dairy industry (BAHS 2024).

The productivity of a dairy herd is determined by economic traits such as total milk yield (TMY), 305-day total milk yield (TMY_305), lactation peak yield (LPY), lactation length (LL), calving interval (CI), dry period (DP), average daily milk yield per lactation length (ADMY_LL), and average daily milk yield per calving interval (ADMY_CI). These traits vary across breeds and individual animals due to genetic differences, management practices, environmental conditions, feeding regimes, and geographical distribution (Chitra et al., 2018).

To enhance the productivity of dairy animals, understanding the influence of non-genetic factors on economic traits is essential. Factors such as season, period of calving, parity, and management practices significantly impact milk production, reproductive efficiency, and overall performance. Identifying these factors is critical for optimizing management strategies and implementing effective selection programs to improve productivity and ensure sustainable genetic progress in future generations. Therefore, the present study aims to evaluate the impact of non-genetic factors on economic traits in Surti buffaloes, and estimate the least squares means of these traits.

MATERIAL AND METHODS

The present study was conducted using data from the Network Project on Buffalo Improvement (Surti) at the Livestock Research Station, Vallabhnagar, Udaipur (RAJUVAS, Bikaner), covering records spanning from 1993 to 2023. The dataset included animals with well-documented pedigrees and detailed economic trait records to ensure accuracy and reliability in the analysis. Outliers were systematically excluded to maintain data integrity. Records with abnormalities such as abortions, stillbirths, lactation lengths of less than 100 days, total milk yields below 500 kg, or any other pathological conditions affecting economic traits were excluded. Additionally, sires with fewer than three progeny were not considered in the analysis to improve the robustness of genetic evaluations.

The study analyzed economic traits, including total milk yield (TMY), 305-day total milk yield (TMY_305), peak yield (PY), lactation length (LL), calving interval (CI), dry period (DP), average daily milk yield per lactation length (ADMY_LL), and average daily milk yield per calving interval (ADMY_CI). These traits were evaluated in relation to age, season, period of calving, and dam's parity.

The data were analyzed to assess the influence of non-genetic factors using the Mixed Model Least-Squares and

Maximum Likelihood method (Harvey 1990). The statistical mixed model applied was as follows:

$$Y_{ijklmn} = \mu + A_i + B_j + C_k + D_l + E_m + e_{ijkl}$$

Where,

Y_{ijklmn} = performance record of the n^{th} progeny of i^{th} sire belonging to j^{th} period of calving, k^{th} season of calving, l^{th} parity of animal, m^{th} age group of each calving.

μ = Population mean common to all observations

A_i = Random effect of i^{th} sire

B_j =Fixed effect of j^{th} period of calving (j = 1, 2, 3, 4, 5 and 6)

C_k = Fixed effect of k^{th} season of calving (= 1, 2 and 3)

D_l = Fixed effect of l^{th} parity (l= 1, 2, 3, 4, 5, 6 and above)

E_m = Fixed effect of m^{th} age group on each calving

e_{ijklmn} = Residual random error associated with Y_{ijklmn} and assumed to be identically and independently distributed with mean zero and constant variance.

Estimation of phenotypic trends: Phenotypic trends were estimated by analysing the changes in the observed phenotypic performance of the traits over time. After standardization of data, the phenotypic trend was calculated by taking regression of time mean performance of the population on the time as:

$$P = b_{P.T}$$

The standard error of the phenotypic trend was calculated as:

$$\text{SE of } (\Delta P) = \left[\frac{\sum P^2 - b_{P.T}(\sum PT)}{\left(\sum T^2\right)(N-2)}\right]^{1/2}$$

The regression analysis was performed using the lm function in R to explore the relationship between the average phenotypic performance of the trait on the time of birth.

Statistical analysis: Duncan's Multiple Range Test (DMRT), as modified by Kramer (1957), was used to make pairwise comparisons among the least-squares means. function using agricolae package in R software. The difference between the means of treatment *i* (Xi) and treatment *j* (Xj) was considered significant at the 5% level (P ≤ 0.05) if it satisfied the following condition:

$$(X_i - X_j)\sqrt{\frac{2}{(C_{ii} + C_{jj} + 2C_{ij})}} > \sigma e Z p n_2$$

RESULTS AND DISCUSSION

General performance: The overall least-squares means for total milk yield, total milk yield at 305 days, lactation peak yield, lactation length, calving interval, dry period, average daily milk yield per lactation length, and average daily milk yield per calving interval were 1466.59 kg, 1605.97 kg, 9.46 kg, 290.42 days, 503.10 days, 206.02 days, 5.08 kg, and 3.14 kg, respectively (Table 1, 2). Total milk yield, was in consistent with findings by Rathod et al. (2018) and Pawar et al. (2018). However, Kumar, (2018) reported lower estimates, potentially due to differences in environmentalconditions and feeding management). Similarly, total milk yield at 305 days was in accordance with earlier findings by Tailor and Singh (2014) and Rathod et al. (2018), suggesting the breed's potential for improved milk production under optimal management. Lactation peak yield, indicating the highest daily milk yield during lactation, was 9.46 kg, aligning with results from Kumar (2018) and Brar et al. (2022) in Surti and Murrah buffaloes, respectively. The higher LPY reflects better genetic potential and management conditions (Kaur and Narang, 2021). In contrast, lactation length (LL) was 290.42 days, which is comparable to findings from Shashikant (2022) and Chakraborty and Dhaka (2023), but slightly lower than previous reports (Pawar et al., 2018, Kumar 2018). Variability in lactation length across studies may be due to differences in milking frequency, feed availability, and environmental stressors. Calving interval, a crucial reproductive trait affecting milk production efficiency, was estimated at 503.10 days. These results support previous, emphasizing the need for genetic and environmental improvements to shorten CI studies (Rathod et al., 2018, Vyas et al., 2021). Similarly, dry period, representing the non-lactating phase between successive calvings, was recorded as 206.02 days, aligning with earlier findings in Surti buffaloes (Kumar 2018, Shashikant 2022). Shorter dry periods contribute to higher lifetime milk production and improved herd efficiency.

Among production efficiency indicators, average daily milk yield per lactation length was 5.08 kg, which aligns with earlier studies, indicating stable productivity over lactation (Jakhar et al., 2017, Kaur and Narang 2021). Meanwhile, average daily milk yield per calving interval was 3.14 kg, consistent with results from Thiruvenkadan (2011) and Kumar (2018). Higher ADMY_CI which indicate improved productivity efficiency across lactations.

Effect of Various Factors on Economic Traits

Random effect of sire: The sire effect was significant for most economic traits, indicating genetic variability among Surti buffaloes. Significant sire effects on total milk yield, 305-day total milk yield, peak yield, lactation length, calving interval, dry period, and average daily milk yield traits were reported in several studies (Nagda 2005, Shashikant 2022). Highly significant sire effect was observed for TMY and LPY, consistent with findings in Surti buffaloes (Bharat et al., 2004) and Murrah buffaloes (Verma et al., 2017, Brar et al., 2022). However, non-significant sire effects on some traits were noted in Surti buffaloes (Jatolia 2008) and Murrah buffaloes (Jakhar et al., 2017). The genetic variation among sires influences milk production efficiency, reinforcing the need for sire selection based on breeding values and progeny testing.

Age: The effect of age on most traits was non-significant, although an increasing trend in milk yield and lactation performance was observed as animals matured. Buffaloes aged 110-124 months produced the highest TMY (1636.32 kg), TMY_305 (1760.65 kg), and LPY (10.49 kg/day). Similar trend was observed in Mehsana buffaloes (Singh, 1992) and Murrah buffaloes (Prakash et al., 1988) and Nili-Ravi buffaloes (Singh et al., 2011). Younger buffaloes (<50 months) had lower yields, likely due to incomplete physiological maturity and suboptimal udder development (Kumar, 2018). Lactation length and calving interval also increased with age, with older buffaloes showing longer LL (306.24 days) and shorter CI (464.54 days), consistent with findings in Surti buffaloes (Vyas et al., 2021) and Murrah buffaloes (Thiruvenkadan et al., 2014).

Period of calving: The period of calving had a highly significant effect on all economic traits, reflecting long-term genetic trends, environmental changes, and management practices. The highest TMY (1759.10 kg) was in buffaloes calving during 1993-1997, whereas the lowest (1368.14 kg) in 2018-2023, marking a 22.2% decline. Similar declining trends in TMY have been reported in Surti buffaloes (Kumar, 2018; Shashikant, 2022) and Pandharpuri buffaloes (Gaikwad et al., 2022).

Table 1. Production traits in Surti buffaloes (Least-squares mean and SE)

Effect	TMY	TMY_305	LPY	LL
N	868	350	868	868
μ±S.E.	1466.59	1605.97	9.46	290.42
Age (Month)	NS	NS	***	NS
1 (35-49)	1409.02(97)	1578.41(36)	8.59^{a} (97)	284.25(97)
2 (50-64)	1478.34(161)	1585.19(75)	8.88^{a} (161)	296.79(161)
3 (65-79)	1487.17(154)	1626.31(64)	9.22^{b} (154)	281.77(154)
4 (80-94)	1541.02(135)	1629.34(52)	9.70^{c} (135)	291.17(135)
5 (95-109)	1570.73(113)	1644.29(38)	9.93^{c} (113)	294.62(113)
6 (110-124)	1636.32(85)	1760.65(33)	10.49^{d} (85)	298.97(85)
7 (125 and above)	1607.42(123)	1722.29(52)	9.94^{c} (123)	306.24(123)
Season	***	**	***	*
Summer (S_1)	1509.39^{a} (106)	1592.76^{a} (40)	9.40^{a} (106)	292.41^{ab} (106)
Rainy (S_2)	1466.83^{a} (473)	1634.04^{a} (174)	9.32^{a} (473)	286.74^{a} (473)
Winter (S_3)	1622.36^{b} (289)	1721.73^{b} (136)	9.90^{b} (289)	301.06^{b} (289)
Period	**	**	***	*
(1993-1997) P_1	1759.10^{d} (22)	1821.43^{d} (13)	9.51^{b} (22)	310.85^{bc} (22)
(1998-2002) P_2	1637.36^{c} (159)	1723.37^{c} (80)	9.64^{b} (159)	309.02^{b} (159)
(2003-2007) P_3	1508.70^{b} (246)	1678.74^{c} (79)	10.37^{c} (246)	280.28^{a} (246)
(2008-2012) P_4	1426.86^{ab} (158)	1531.04^{a} (56)	9.55^{b} (158)	287.63^{a} (158)
(2013-2017) P_5	1496.99^{b} (130)	1647.5^{c} (57)	9.47^{b} (130)	282.15^{a} (130)
(2018-2023) P_6	1368.14^{a} (153)	1494.90^{a} (65)	8.69^{a} (153)	290.48^{a} (153)
Parity	NS	NS	**	NS
1	1403.82(254)	1508.27(108)	9.00^{a} (254)	296.74 (254)
2	1548.07(183)	1625.49(78)	9.665^{bc} (183)	305.02 (183)
3	1553.08(143)	1717.69(51)	9.785^{c} (143)	290.44 (143)
4	1576.19(104)	1704.08(43)	9.62^{bc} (104)	295.77 (104)
5	1591.84(76)	1658.01(33)	9.74^{bc} (76)	292.76(76)
6 and above	1524.16 (108)	1683.45(37)	9.41^{b} (108)	279.67 (108)
Sire	*	NS	***	*

NS= non-significant, *p<0.05= significant, **p<0.01= highly significant, ***p<0.001= highly significant.
Figures in parenthesis indicate number of observations

The decline in milk yield traits over time suggests possible genetic dilution, environmental stressors, and nutritional variations. Studies on Murrah buffaloes also observed decreasing milk yields over decades due to climate change and shifts in feeding systems (Gandhi et al., 2009, Jakhar et al., 2017). Lactation length also declined significantly over time, from 310.85 days (1993-1997) to 280.28 days (2003-2007), indicating the impact of changing lactation management practices (Patel et al., 1998, Thiruvenkadan et al., 2014). Calving interval increased by 22.8% over different calving periods, similar to findings in Surti buffaloes (Nagda 2005, Vyas et al., 2021). The increasing CI reflects declining reproductive efficiency and suboptimal fertility management over time (Kumar 2018).

Season of calving on economic traits: Season had a highly significant effect on TMY, TMY_305, LPY, LL, and reproductive traits. The highest TMY was in winter (1622.36 kg), whereas the lowest in the rainy season (1466.83 kg), indicating a 10.6% decrease. Similar results have been reported in Surti buffaloes (Kumar 2008, Shashikant 2022) and Murrah buffaloes (Thiruvenkadan et al., 2010, 2011, 2014).

Winter-calving buffaloes had longer lactation lengths (301.06 days) and shorter calving intervals (473.12 days), suggesting better reproductive efficiency in colder months. Higher milk yield in winter can be attributed to optimal temperatures, better feed availability, and reduced heat stress, whereas rainy-season calvings coincide with

Table 2. Reproductive and efficiency traits in Surti buffaloes

Effect	CI	DP	ADMY_CI	ADMY_LL
N	661	661	661	868
μ±S.E.	503.10	206.02	3.14	5.08
Age (Month)	NS	NS	**	NS
1 (35-49)	554.78 (73)	255.86 (73)	2.65^{a} (73)	5.07 (97)
2 (50-64)	540.46 (130)	229.91 (130)	2.91^{a} (130)	5.09 (161)
3 (65-79)	505.04 (120)	202.58 (120)	3.22^{c} (120)	5.34 (154)
4 (80-94)	503.47 (111)	204.80 (111)	3.21^{c} (111)	5.32 (135)
5 (95-109)	464.54 (87)	169.32 (87)	3.54^{d} (87)	5.33 (113)
6 (110-124)	494.28 (68)	197.74 (68)	3.46^{d} (68)	5.46 (85)
7 (125 and above)	480.09 (72)	165.72 (72)	3.59^{d} (72)	5.28 (123)
Season	***	**	*	***
Summer (S_1)	533.41^{c} (71)	219.40^{b} (71)	3.06^{a} (71)	5.25^{a} (106)
Rainy (S_2)	473.12^{a} (365)	181.66^{a} (365)	3.28^{b} (365)	5.14^{a} (473)
Winter (S_3)	511.75^{b} (225)	210.05^{b} (225)	3.34^{b} (225)	5.42^{b} (289)
Period	*	*	**	***
(1993-1997) P_1	446.15^{a} (22)	133.98^{a} (22)	3.86^{c} (22)	5.62^{c} (22)
(1998-2002) P_2	548.08^{c} (139)	229.03^{b} (139)	3.16^{ab} (139)	5.28^{b} (159)
(2003-2007) P_3	510.20 (156)	208.92^{b} (156)	3.25^{b} (156)	5.41^{b} (246)
(2008-2012) P_4	502.56^{b} (126)	207.91^{b} (126)	2.95^{a} (126)	5.03^{a} (158)
(2013-2017) P_5	512.29^{bc} (110)	223.96^{b} (110)	3.17^{ab} (110)	5.4^{b} (130)
(2018-2023) P_6	517.28^{bc} (108)	218.44^{b} (108)	2.97^{a} (108)	4.86^{d} (153)
Parity	NS	NS	NS	**
1	514.27 (193)	217.02 (193)	2.95 (193)	4.71^{a} (254)
2	509.62 (147)	207.19 (147)	3.15 (147)	5.10^{b} (183)
3	510.38 (115)	211.69 (115)	3.24 (115)	5.41^{c} (143)
4	524.59 (81)	214.31 (81)	3.26 (81)	5.39^{c} (104)
5	509.04 (56)	198.00 (56)	3.39 (56)	5.52^{c} (76)
6 and above	468.66 (69)	174.02 (69)	3.39 (69)	5.48^{c} (108)
Sire	NS	NS	**	***

NS= non-significant, *p<0.05= significant, **p<0.01= highly significant, ***p<0.001= highly significant
Figures in parenthesis indicate number of observations

increased humidity, poor nutritional status, and higher disease susceptibility (Verma et al., 2017, Brar et al., 2022). The dry period was also significantly affected by season, with the longest DP in summer (219.40 days) and the shortest in the rainy season (181.66 days). Similar seasonal patterns in DP was observed in Murrah buffaloes (Thiruvenkadan et al., 2014) and Bhadawari buffaloes (Kushwaha et al., 2013).

Parity: Parity did not have a significant effect on most traits, but a general increasing trend in milk yield was observed until the fifth parity, after which a decline was noted. The highest TMY (1591.84 kg), TMY_305 (1717.69 kg), and LPY (9.74 kg/day) were in buffaloes of the fifth parity, aligning with findings in Murrah buffaloes (Pawar et al., 2012, Brar et al., 2022) and Mehsana buffaloes (Galsar et al., 2016). Reproductive traits showed a decreasing trend in calving interval and dry period with increasing parity, indicating improved reproductive efficiency in older buffaloes (Kumar 2018, Vyas et al., 2021). However, the average daily milk yield traits (ADMY_LL, ADMY_CI) were highest in third to fifth-parity buffaloes, after which a decline was noted due to age-related metabolic constraints (Thiruvenkadan et al., 2014).

Phenotypic trends in surtax buffaloes: Phenotypic trends for key economic traits in Surti buffaloes were analyzed across multiple two-year intervals, the total milk yield exhibited yield exhibited statistically significant negative trend of -21.47 kg per period, indicating a consistent decline in overall milk production across years (Table 3). This downward trajectory may reflect the combined impact of environmental stressors, suboptimal management, and possible dilution of genetic potential over time. Similar declining trends in milk yield were reported in Murrah buffaloes suggesting a broader concern across Indian dairy breeds (Chander 2002, Godara et al., 2015).

The 305-day Milk Yield (TMY_305) also showed a significant negative phenotypic trend of -18.04 kg per period, reaffirming the reduction in standardized lactation output. These findings are consistent with earlier observations in

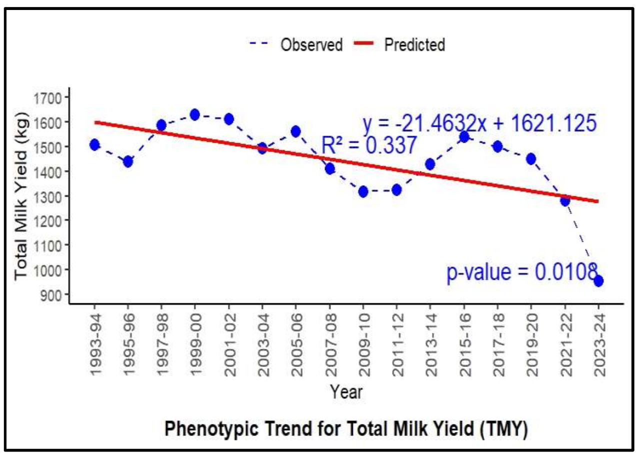

Fig. a. Phenotypic trends for total milk yield

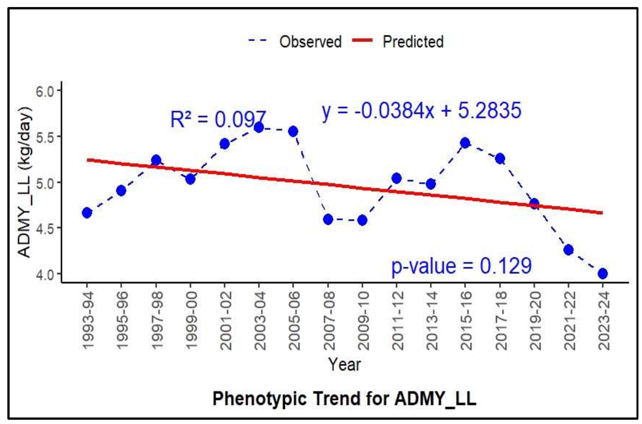

Fig. c. Phenotypic trends for average daily milk yield per lactation length

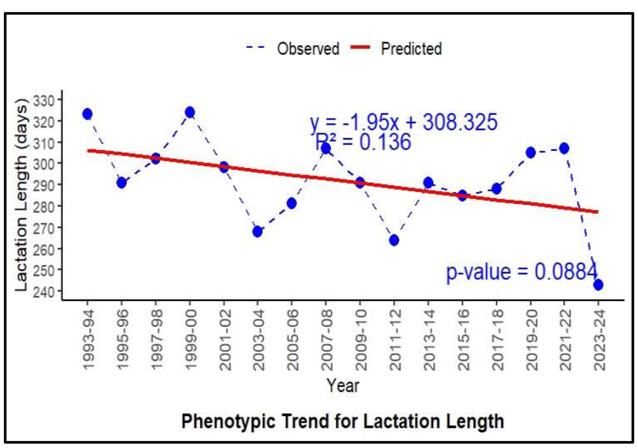

Fig. b. Phenotypic trends for lactation length

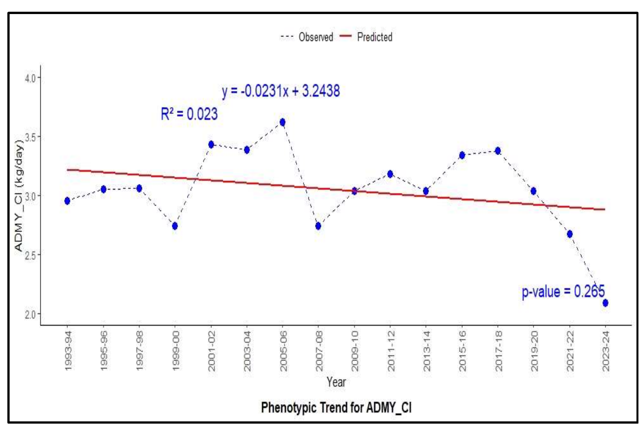

Fig. d. Phenotypic trends for average daily milk yield per calving interval

Table 3. Phenotypic trends of economic traits

Traits	Phenotypic	P-Value	R^2
TMY	-21.47	0.01	0.337
TMY_305	-18.04	0.05	0.181
LPY	-0.05	0.38	-0.013
LL	-1.96	0.08	0.136
CI	-2.92	0.278	0.019
DP	-1.45	0.506	-0.037
ADMY_LL	-0.04	0.129	0.097
ADMY_CI	-0.02	0.265	0.023

Hariana and Sahiwal cattle emphasizing the need for renewed genetic selection and improved nutrition strategies (Singh et al., 2002, Raja et al., 2009). For lactation peak yield, a small but negative trend of -0.05 kg per period was recorded. Although not statistically significant, this slight reduction in peak daily milk yield suggests that genetic improvement programs may have overlooked peak yield while focusing predominantly on total yield. Comparable pattern was recently observed by Sharma et al. (2024) in Murrah buffaloes, underlining the importance of including peak yield in selection indices. The lactation length displayed a non-significant but negative phenotypic trend of -1.96 days per period, indicating a gradual shortening of productive periods over the years and may result from changes in environmental conditions, such as heat stress or fluctuating feed availability, which are known to affect lactation duration. Although subtle, this trend warrants attention as it may ultimately reduce lifetime productivity.

The negative phenotypic trend of -2.92 days per period was observed for the calving interval, indicating an apparent improvement in reproductive efficiency through shortened intervals between successive calvings. This decline was not statistically significant but is favorable development likely attributed to better reproductive management and health practices. These findings are supported by studies in Murrah and Sahiwal cattle by Dev et al. (2017) and Dash et al. (2021), respectively.

The dry period also demonstrated a non-significant negative trend of -1.45 days per period, suggesting a marginal reduction in non-lactating periods. Shorter dry periods contribute to better annual milk yield efficiency and reflect improved herd health and management. Similar beneficial trends have was observed by Singh et al. (2011) and Sharma et al. (2024).

In terms of milk yield efficiency, both Average Daily Milk Yield during Lactation Length and Average daily milk yield during calving interval presented negative phenotypic trends of -0.04 kg and -0.02 kg per period, respectively. Although these trends were not statistically significant, but signal a slow decline in daily milk productivity. This may stem from cumulative environmental stresses, inconsistent genetic selection, or inadequate adaptation of breeding programs to changing climatic conditions.

Overall, the phenotypic trends observed in Surti buffaloes point to a concerning decline in milk production traits, with only marginal improvements in reproductive efficiency. These findings underscore the need for targeted interventions, including enhanced genetic selection, nutritional improvements, and adaptive management strategies, to reverse these unfavorable trends and sustain productivity in the breed.

CONCLUSION

This study demonstrates the significant influence of sire, age, period of calving, season of calving, and parity on key economic traits in Surti buffaloes. The sire effect emphasizes genetic variability, highlighting the importance of progeny testing for genetic improvement. The declining trend in total milk yield over periods emphasizes the need for enhanced management and breeding strategies. Winter-calving buffaloes performed better across most traits, reinforcing seasonal adaptation in herd management. Improved nutrition, reproductive management, and genetic selection are essential to sustain productivity. These findings contribute to scientific breeding programs and productivity enhancement in Surti buffaloes.

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Received 02 July, 2025; Accepted 23 September, 2025