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Relationship between Milk Yield and Udder Morphology Traits in White Fulani Cows

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Abstract: The study examined the relationship between milk yield and udder morphology traits in White Fulani cows. Fifty-eight apparently healthy cows in early lactation at 2nd, 3rd, and 4th parity were used in the study. The data obtained from the cows were test day milk yield (TDMY) from single milking and udder morphology traits comprising udder length (UL), udder width (UW), udder depth (UD), fore teat length (FTL), rear teat length (RTL), fore teat diameter (FTD), and rear teat diameter (RTD). There was no significant effect of parity on TDMY or the udder morphology traits. Phenotypic correlations between TDMY, UL, UW, and UD were positive and significant. Notably, phenotypic correlations between UL and TDMY at different parities were the strongest. Teat measurements had no significant correlation with TDMY. Stepwise and principal component regressions were implemented to assess the relationship between milk yield and udder morphology traits. Interestingly, UL was the only trait that entered the reduced models. The results suggest a probable genetic correlation between milk yield and udder length. Therefore, since udder conformation traits are heritable, when selecting for udder length in White Fulani cows, a correlated response in milk yield is expected.

Keywords: white Fulani cows; udder morphology traits; udder length; milk yield; phenotypic correlation; genetic correlation

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1. Introduction

The demand for milk in developing countries is projected to rise by 25 percent by 2025 [1]. Unfortunately, the dairy sector in Nigeria is challenged by poor yields from local breeds and high production costs on commercial farms with exotic breeds. Most dairy cows in commercial use are exotic taurine breeds due to their outstanding milk yield [2]. However, they have poor survivability and suboptimal performance in tropical environments, especially in Sub-Saharan Africa. In this region, indiscriminate crossbreeding is also implemented to leverage the productivity of exotic breeds and the hardiness of indigenous breeds. However, it has been challenged by high mortality and production costs [3]. Furthermore, indiscriminate crossbreeding poses an existential threat to indigenous African breeds in their purest form, as exhibited in 209 cattle breeds [4].

In Nigeria, the White Fulani (Bunaji) is the most productive indigenous breed used in dairy production [5]. The White Fulani is predominantly found in Nigeria, Cameroon, and the Central African Republic, with a combined population of 9.6 million [6]. The White Fulani make up about 37.2% of the cattle population in Nigeria. It has an average milk yield ranging from 1.92 to 2.96 kg per lactation [7–11]. Although it rates low by world dairy standards, when compared to other indigenous breeds such as the Red Bororo (Rahaji) and Sokoto Gudali (Bokoloji), it ranks high in milk production [9–12]. There is a future for this breed as a global dairy cattle, as indicated in studies by Epstein [13], Petit [14], and Queval et al. [15], suggesting a common heritage in evolutionary history with the taurine cattle, different from the typical zebu. This indicates potential production levels comparable to those seen in taurine breeds.

Body measurements are phenotypic markers of the genetic makeup of an animal. Consequently, udder morphology traits are promising indicators of milk yield in dairy cattle. Bhuiyan et al. [16] explained that the size and shape of the udder are important conformation traits that could play a vital role in assessing a dairy animal's suitability for commercial milk production and should be considered in selection. According to Tilki et al. [17], udder traits play an important role in dairy cattle because milk yield is affected by the morphological properties of udder traits. Studies by Byskov et al. [18], Ducro et al. [19], and Khan and Khan [20] showed that the physical traits of the udder and teats in cattle are moderate to highly heritable and highly repeatable, whereas low or moderate levels were reported for milk yield by Meseret and Negussie [21], Roman et al. [22], and Salem and Hammoud [23].

Extensive research on the White Fulani, considering its dairy potential, has tremendous prospects for improved dairy production in Nigeria and across West Africa. The current understanding of the relationship between anatomical features, especially udder morphology, and milk yield in White Fulani cows is severely limited. Gaining insights into this area will enhance our understanding of the current status and untapped potential of the White Fulani in the context of dairy production. Thus, the study assessed the relationship between milk yield and udder morphology traits in White Fulani cows to identify prospective selection criteria for increased milk yield.

2. Materials and Methods

2.1. Animals and Management

The study was conducted at Akele, Oyo Town, Oyo State, Nigeria. Fifty-eight apparently healthy White Fulani cows in early lactation at 2nd, 3rd, and 4th parity were used in the study. The cows were raised by Fulani pastoralists at the project site. The animals were appropriately marked. The cows were fed entirely by grazing. The calves were restricted from the dams before and after natural suckling. They were allowed residual suckling for about 30 min after hand-milking the dam in the morning and were allowed access to proper suckling for about 30 min in the evening.

2.2. Udder and Teat Morphometry

Measurements on the udder and teats were taken in centimeters (cm) with a measuring tape and a Vernier caliper on each animal, once in the morning (between 5 a.m. and 8 a.m.) just before milking. The measurements were udder length (UL), udder width (UW), udder depth (UD), fore teat length (FTL), rear teat length (RTL), fore teat diameter (FTD), and rear teat diameter (RTD). UL was measured by passing the tape between the left and right pairs of teats from the rear attachment of the udder to the front of the udder, where the fore udder blends smoothly with the abdominal wall. UW was measured by passing the tape between the rear teats and fore teats from the stifle joint on one side to the opposite stifle joint. UD was measured by subtracting the ground-to-udder floor distance from the ground-to-udder base distance. Teat length was measured with the tape from the upper part of the teat, where it hangs perpendicularly from the udder to the tip of the teat. The lengths of the two fore teats and two rear teats were measured and averages were calculated on each pair to obtain FTL and RTL, respectively. The diameter of the teat was measured to the nearest 0.01 cm around the midpoint of the teat length using a Vernier caliper. The diameters of the two fore and two rear teats were measured and averages were calculated on each pair to obtain FTD and RTD, respectively.

2.3. Milk Yield Measurement

Test-day milk yield (TDMY) measurements were repeated on each animal for 30 days. Hand milking was used, and milk yield was measured in kilograms (kg) with a kitchen scale, once in the morning (5 a.m. to 8 a.m.). The milking routine is as follows; brief suckling by calves to initiate milk let-down from lactating cows, udder preparation, and then hand milking.

2.4. Experimental Design and Statistical Analysis

Mixed-model design ANOVA was used to evaluate the effect of parity on TDMY.

Statistical model: $y = X\beta + Zu + \varepsilon$.

Where:

y = Vector of the studied dependent variable (TDMY).
X = Design matrix, which relates y to β.
β = Vector of fixed effects of parity (i = 2, 3, 4).
Z = Design matrix, which relates y to u.
u = Vector of random effects of subjects (cows) with mean 0 and variance-covariance matrix G.
ε = Vector of random errors with mean 0 and variance-covariance matrix R.

Completely randomized design one-way ANOVA was used to evaluate the effect of parity on udder morphology traits.

Statistical model: $Y_{ij} = \mu + \tau_i + \varepsilon_{ij}$.

Where:

Y_{ij} = Studied dependent variables (UL, UW, UD, FTL, RTL, FTD, and RTD).
μ = Population mean.
τ_i = Effect of parity (i = 2, 3, 4).
ε_{ij} = Experimental error with mean 0 and variance σ^2.

Phenotypic correlations between milk yield and udder morphology traits were evaluated by computing Pearson correlation coefficients (r).

Stepwise and principal component regressions were implemented to evaluate the functional relationship between TDMY and udder morphology traits. Factor or principal component (PC) extraction was accomplished by principal component analysis (PCA). Assessment of the data for PCA suitability was done using the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy [24] and Bartlett's test of sphericity [25]. Varimax rotation was used to facilitate the interpretation of factor loadings (L_{ik}). Factor score coefficients (C_{ik}) were used to obtain factor scores. Factor scores were used as the independent variables for principal component regression. Regression coefficients were tested for significance using the t-test. The coefficient of determination (R^2) was used as the predictive success criterion to compare regression models.

Full model for stepwise regression: $Y_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \cdots + \beta_7 x_{7i} + \varepsilon_i$.

Model for principal component regression: $Y_i = \beta_0 + \beta_1 PC_{1i} + \cdots + \beta_n PC_{ni} + \varepsilon_i$.

Where:

Y_i = *ith* observation of TDMY.
$x_{1i} \ldots x_{7i}$ = *ith* observation of the studied independent variables (UL, UW, UD, FTL, RTL, FTD, and RTD.
$PC_{1i} \ldots PC_{ni}$ = *ith* factor scores of the principal components.
$\beta_0 \ldots \beta_7$ = regression parameters.
ε_i= random error.

The data were analyzed with SPSS [26].

3. Results

Table 1 shows descriptive statistics on TDMY and udder morphology traits. The average TDMY slightly increased as parity increased. In addition, the table shows a slight increment in UL and UW as the parity increased, except for UD, which increased up to the 3rd parity and declined in the 4th parity. Mean FTL and RTL showed a similar pattern as UD, whereas mean FTD and RTD decreased with increasing parity. Table 2 presents the effect of parity on milk yield and udder morphology traits in White Fulani cows. Parity has no significant effect on milk yield or udder morphology traits.

Table 1. Descriptive statistics on milk yield (kg) and udder morphology traits (cm) in White Fulani cows.

Parity	Udder Traits	*n*	Min	Max	Mean ± S. E.	S. D.	C. V. (%)
2	TDMY	540	2.59	4.81	3.837 ± 0.016	0.37	9.54
	UL	18	31.40	48.20	40.40 ± 1.18	4.95	12.26
	UW	18	37.30	59.10	48.97 ± 1.46	6.21	12.67
	UD	18	17.10	22.30	19.41 ± 0.39	1.64	8.44
	FTL	18	4.30	6.45	5.63 ± 0.17	0.72	12.74
	RTL	18	3.70	5.50	4.64 ± 0.14	0.59	12.81
	FTD	18	1.67	2.57	2.11 ± 0.06	0.24	11.49
	RTD	18	1.61	2.40	2.01 ± 0.05	0.23	11.46
3	TDMY	450	2.89	4.81	3.845 ± 0.018	0.39	10.10
	UL	15	32.70	47.40	41.28 ± 1.27	4.91	11.89
	UW	15	37.60	58.10	49.57 ± 1.59	6.16	12.43
	UD	15	17.10	24.00	20.44 ± 0.58	2.25	11.03
	FTL	15	4.30	6.40	5.71 ± 0.19	0.74	13.04
	RTL	15	3.65	5.85	4.82 ± 0.17	0.64	13.36
	FTD	15	1.77	2.50	2.11 ± 0.06	0.22	10.60
	RTD	15	1.64	2.29	1.91 ± 0.05	0.20	10.53
4	TDMY	750	2.56	4.87	3.870 ± 0.014	0.39	9.96
	UL	25	33.60	50.40	41.84 ± 0.97	4.86	11.62
	UW	25	38.40	61.60	50.76 ± 1.24	6.18	12.18
	UD	25	16.30	23.20	20.17 ± 0.36	1.79	8.89
	FTL	25	4.10	6.55	5.62 ± 0.13	0.64	11.30
	RTL	25	3.35	5.90	4.80 ± 0.12	0.60	12.49
	FTD	25	1.72	2.60	2.09 ± 0.05	0.25	11.93
	RTD	25	1.64	2.42	1.90 ± 0.04	0.22	11.70

TDMY = test day milk yield, UL = udder length, UW = udder width, UD = udder depth, FTL = fore teat length, RTL = rear teat length, FTD = fore teat diameter, RTD = rear teat diameter. *n* = number of observations, S. E. = standard error of mean, Min = minimum value, Max = maximum value, SD = standard deviation, and C. V. = coefficient of variation.

Table 2. Effect of parity on udder traits (cm) and milk yield (kg) in White Fulani cows (*n* = 18, 15, and 25 for parity 2, 3, and 4, respectively).

Parameters	Parity 2	Parity 3	Parity 4	*p* Value
TDMY	3.837 ± 0.016	3.845 ± 0.018	3.870 ± 0.014	0.873^{ns}
UL	40.40 ± 1.18	41.28 ± 1.27	41.84 ± 0.97	0.640^{ns}
UW	48.97 ± 1.46	49.57 ± 1.59	50.76 ± 1.24	0.629^{ns}
UD	19.41 ± 0.39	20.44 ± 0.58	20.17 ± 0.36	0.251^{ns}
FTL	5.63 ± 0.17	5.71 ± 0.19	5.62 ± 0.13	0.911^{ns}
RTL	4.64 ± 0.14	4.82 ± 0.17	4.80 ± 0.12	0.606^{ns}
FTD	2.11 ± 0.06	2.11 ± 0.06	2.09 ± 0.05	0.942^{ns}
RTD	2.01 ± 0.05	1.91 ± 0.05	41.84 ± 0.97	0.199^{ns}

^{ns} means in the same row are not significantly ($p > 0.05$) different. UL = udder length, UW = udder width, UD = udder depth, FTL = fore teat length, RTL = rear teat length, FTD = fore teat diameter, RTD = rear teat diameter, *n* = number of cows (replicates).

The phenotypic correlations (r_p) observed between TDMY and udder morphology traits are shown in Table 3. UL, UW, and UD had highly significant ($p < 0.01$) and positive r_p with TDMY across the parities. Teat measurements, viz., FTL, RTL, FTD, and RTD, had no significant r_p with TDMY. Significant ($p < 0.05$, $p < 0.01$) positive correlations were observed between UL, UW, and UD. Phenotypic correlations involving teat measurements were mostly not significant.

Table 3. Phenotypic correlation between mean TDMY and udder traits in White Fulani cows.

Parity		TDMY	UL	UW	UD	FTL	RTL	FTD	RTD
2	TDMY	1							
	UL	0.701 **	1						
	UW	0.698 **	0.940 **	1					
	UD	0.639 **	0.807 **	0.799 **	1				
	FTL	0.425 ^{ns}	0.721 **	0.696 **	0.560 *	1			
	RTL	0.437 ^{ns}	0.722 **	0.665 **	0.564 *	0.891 **	1		
	FTD	0.358 ^{ns}	0.329 ^{ns}	0.164 ^{ns}	0.151 ^{ns}	0.201 ^{ns}	0.132 ^{ns}	1	
	RTD	0.352 ^{ns}	0.329 ^{ns}	0.249 ^{ns}	0.226 ^{ns}	0.329 ^{ns}	0.186 ^{ns}	0.737 **	1
3	TDMY	1							
	UL	0.892 **	1						
	UW	0.829 **	0.926 **	1					
	UD	0.693 **	0.761 **	0.555 *	1				
	FTL	0.117 ^{ns}	0.043 ^{ns}	0.024 ^{ns}	−0.149 ^{ns}	1			
	RTL	0.229 ^{ns}	0.067 ^{ns}	0.040 ^{ns}	0.004 ^{ns}	0.932 **	1		
	FTD	0.427 ^{ns}	0.354 ^{ns}	0.045 ^{ns}	0.562 *	0.233 ^{ns}	0.294 ^{ns}	1	
	RTD	0.337 ^{ns}	0.253 ^{ns}	−0.044 ^{ns}	0.595 *	0.117 ^{ns}	0.194 ^{ns}	0.922 **	1
4	TDMY	1							
	UL	0.773 **	1						
	UW	0.695 **	0.890 **	1					
	UD	0.659 **	0.607 **	0.431 *	1				
	FTL	0.390 ^{ns}	0.391 ^{ns}	0.444 *	0.251 ^{ns}	1			
	RTL	0.363 ^{ns}	0.460 *	0.393 ^{ns}	0.346 ^{ns}	0.695 **	1		
	FTD	−0.206 ^{ns}	−0.111 ^{ns}	−0.110 ^{ns}	−0.303 ^{ns}	0.047 ^{ns}	0.349 ^{ns}	1	
	RTD	−0.156 ^{ns}	−0.101 ^{ns}	−0.015 ^{ns}	−0.195 ^{ns}	0.080 ^{ns}	0.302 ^{ns}	0.890 **	1

^{ns} Not significant ($p > 0.05$), * Significant ($p < 0.05$), ** Significant ($p < 0.01$). TDMY = test day milk yield, UL = udder length, UW = udder width, UD = udder depth, FTL = fore teat length, RTL = rear teat length, FTD = fore teat diameter, and RTD = rear teat diameter.

The results of the factor analysis are shown in Table 4. The KMO measure of sampling adequacy (0.703, 0.319, and 0.470 for parities 2, 3, and 4, respectively) and Bartlett's test of sphericity ($p < 0.01$; across the three parities) obtained from the correlation matrix permitted only udder and teat measurements corresponding to parity 2 for a reasonable factor analysis. Two factors (principal components), explaining 81.62% of the total variance in udder measurements, were generated. The first factor accounted for 59.66% of the total variance in udder measurements, while the second factor explained 21.96% of the total variance. Factor 1 was highly correlated with UL, UW, UD, FTL, and RTL, whereas Factor 2 was highly correlated with FTD and RTD. Bold factor loadings indicate a high correlation between a variable and the corresponding factor. The communality values for the variables were very high, indicating that their variances were effectively reflected by the factors.

Table 5 presents the results of regressing TDMY on the factors. The principal component regression was positive and significant ($p < 0.01$). Factor 1 had a significant ($p < 0.01$) and positive explanatory effect on TDMY. Although positive, the explanatory effect of Factor 2 on TDMY was not significant. The results of the stepwise regression of TDMY on udder traits are shown in Table 6. The regression model was significant ($p < 0.05$) and positive. UL was the only trait that entered the reduced model across the three parities. A positive and significant ($p < 0.01$) explanatory effect of UL on TDMY was observed across the parities.

Table 4. Results of factor analysis of udder and teat measurements in White Fulani cows.

Parity	Variables	Factor Score Coefficients (C_{ik})		Rotated Factor Loadings (L_{ik}) and Communalities		
		Factor 1	Factor 2	Factor 1	Factor 2	Communalities
2	UL	0.230	0.029	**0.920**	0.236	0.903
	UW	0.247	−0.053	**0.921**	0.102	0.858
	UD	0.224	−0.051	**0.835**	0.087	0.705
	FTL	0.220	−0.005	**0.854**	0.167	0.757
	RTL	0.238	−0.080	**0.865**	0.046	0.751
	FTD	−0.093	0.557	0.084	**0.932**	0.876
	RTD	−0.066	0.535	0.170	**0.913**	0.863
Parity 2: KMO measure of sampling adequacy = 0.703 Bartlett's test of sphericity: 0.000 **						
Parity 3: KMO measure of sampling adequacy = 0.319 Bartlett's test of sphericity = 0.000 **						
Parity 4: KMO measure of sampling adequacy = 0.470 Bartlett's test of sphericity = 0.000 **						

Extraction method: PCA. ** Significant ($p < 0.01$). KMO value < 0.5 indicates unsuitability of the data for factor analysis. Bold factor loadings indicate a high correlation between a variable and the corresponding factor. UL = udder length, UW = udder width, UD = udder depth, FTL = fore teat length, RTL = rear teat length, FTD = fore teat diameter, and RTD = rear teat diameter.

Table 5. Summary of linear regression of TDMY on the factors.

Parity	Predictor	Regression Coefficients	S. E.	*p* Value
2	FS1	0.124	0.038	0.005 **
	FS2	0.061	0.038	0.129 ns
	Intercept	3.837	0.037	0.000 **
S = 0.15561, R^2 = 0.472, R^2 (adj) =0.402, *p* value of model = 0.008 **				

ns Not significant ($p < 0.05$), ** Significant ($p < 0.01$), FS1 = factor score 1 derived from factor 1 score coefficients (C_{ik}), FS2 = factor score 2 derived from factor 2 score coefficients (C_{ik}), S. E. = standard error of the regression coefficients, S = standard error of the estimate.

Table 6. Summary of the reduced models from stepwise regression for milk yield on udder traits in White Fulani cows.

Parity	Regression Coefficients								R^2	Adjusted R^2	S	*p* Value
	Constant	UL	UW	UD	FTL	RTL	FTD	RTD				
2	2.687 **	0.028 **	-	-	-	-	-	-	0.491	0.460	0.14789	0.001 **
3	2.212 **	0.040 **	-	-	-	-	-	-	0.796	0.780	0.10220	0.000 **
4	2.462 **	0.034 **	-	-	-	-	-	-	0.597	0.580	0.13722	0.000 **

** Significant ($p < 0.01$), S = standard error of estimates, - = stepwise excluded variables (did not improve the coefficient of determination). UL = udder length, UW = udder width, UD = udder depth, FTL = fore teat length, RTL = rear teat length, FTD = fore teat diameter, and RTD = rear teat diameter, and R^2 = coefficient of determination.

4. Discussion

The study obtained descriptive measures of udder traits and milk yield in White Fulani cows across different parities. It addresses a significant knowledge gap in reliable udder morphometry for Nigerian indigenous cattle breeds, particularly the White Fulani. The comprehensive morphometry presented in this paper not only offers valuable insights into the udder morphology of White Fulani cows but also provides reliable benchmarks for the studied traits.

The overall mean ± standard error for TDMY was 3.853 ± 0.009 kg. The mean TDMY was higher than the mean daily milk yields of 3.54 ± 0.02 kg, 2.18 ± 0.24 kg, 2.74 kg, 1.92 ± 0.55 kg, and 2.96 kg from single milking obtained for the White Fulani by Bala et al. [27], Abubakar et al. [11], Shitu et al. [9], Abbaya et al. [10], and Osman et al. [8]. The wide variation in milk yield is probably a factor of population, and the higher yield observed in the current study can be attributed to the environment, including the climate, considering that the current study was performed in the south-western part of Nigeria, which has a cooler climate, whereas studies by the other authors were performed in the northern part of the country, which has a hotter climate. Milk yield was substantially higher than the mean yields of 1.71 ± 0.41 kg and 1.35 ± 0.55 kg reported for Red Bororo by Abubakar et al. [11] and Abbaya et al. [10]. Similarly, it was higher than the average milk yield of 1.83 ± 0.29 kg [11], 2.67 kg [9], and 1.66 ± 0.43 [10] reported for Sokoto Gudali. However, it was smaller than the 4.01 kg reported for the Friesian × White Fulani cross [9]. The milk yield of the White Fulani was lower than that of the Holstein Friesian, which is usually considered a yardstick for dairy performance. It was meager compared to the mean daily milk yield of 27.77 kg reported by McNamara et al. [28] for single daily milking of early lactation Holstein cows. These findings validate the superior milk yield of the White Fulani compared to other local breeds in Nigeria while also highlighting its low productivity compared to highly developed dairy breeds such as the Holstein Friesian.

The overall mean ± standard error for UL, UW, UD, FTL, RTL, FTD, and RTD were 41.25 ± 0.64, 49.90 ± 0.80, 20.00 ± 0.25, 5.64 ± 0.09, 4.76 ± 0.08, 2.10 ± 0.03, and 1.94 ± 0.03 cm, respectively. The UL was substantially longer than the 28.76 ± 1.68 to 31.83 ± 1.77 cm reported for the White Fulani by Mallam et al. [29]. Similarly, the UW was substantially wider than the 11.61 ±1.15 to 16.73 ±1.21 cm reported by the same authors. The UD was only slightly shorter than the 20.35 ± 1.05 to 22.51 ± 1.11 cm reported by the same authors. Given the observations so far, perhaps the White Fulani is more suited to a cooler climate, as is the case at the project site, compared to the hotter climate seen in the region where the authors performed their study. It could also be a factor of population genetics or feed, among other environmental factors. The UL and UW of White Fulani cows were substantially lower than those of crossbred cows studied by Patel et al. [30]. The crossbreds had UL and UW of 58.24 ± 0.68 cm and 65.45 ± 0.70 cm, respectively. The UD of White Fulani cows was lower than the 24.02 ± 2.86 cm previously reported for a combination of White Fulani and Red Bororo cows [31] but slightly lower than the 23.06 ± 0.34 cm reported for crossbred cows studied by Patel et al. [30]. The udder body measurements of the White Fulani were smaller than those of the Holstein Friesian [32]. The status of the White Fulani compared to the Holstein Friesian can be attributed to the unspecialized nature of the White Fulani as a dairy breed. Holstein and other renowned dairy breeds have been bred over several decades into the copious milk producers with large udder dimensions that they are today. Teat measurements were similar to those reported by Mallam et al. [29]. The FTL and RTL were similar to those reported by Ceyhan et al. [33] for Holstein Friesian, which were 6.05 ± 0.10 and 4.89 ± 0.00 cm, respectively. This similarity is an indication that teat length has no relationship with the milk production potential of a cow. FTD and RTD were quite lower than 2.62 ± 0.01 and 2.57 ± 0.01 cm, respectively, reported for Holstein Friesian by Ceyhan et al. [33]. The substantial difference in diameter can be attributed to the larger volume of milk produced by this exotic breed, which can be presumed to physiologically require a wider exit. The substantial C.V. (8.44% to 13.36%) observed for all the measurements taken may be indicative of the possibility of improving milk yield and udder traits through selection, as suggested by Chu and Shi [32].

The effect of parity on milk yield and udder morphology traits was not significant. This contrasts with the findings of most other authors whose work was reviewed in this study. Nyamushamba et al. [34] observed that parity fitted as a covariate significantly ($p < 0.05$) affected milk yield in Red Dane and Jersey cattle. Coffie et al. [35] reported a significant ($p < 0.01$) effect of parity on milk yield of several African cattle breeds. Bala et al. [27] also reported that the parity of the dam had a significant ($p < 0.05$) effect on both total milk yield and average daily milk yield of Friesian and Friesian × Fulani cows. Similarly, the results contrasts with the significant ($p < 0.05$) to highly significant ($p < 0.01$) effect of parity on teat length observed by Deng et al. [36], Erdem et al. [37], Patel et al. [30], and Singhai et al. [38]. This can be attributed to the fact that they have not been specially bred for milk production. It can also be attributed to hand milking, which is rather inefficient as a milking system compared to more sophisticated methods such as the use of milking machines and the application of advanced milking systems (AMS), which use milking robots.

Highly significant ($p < 0.01$) and positive correlation coefficients ($r_{p)}$ were observed between milk yield and udder measurements, viz., UL, UW, and UD across the parities. The udder measurements were also observed to be significantly ($p < 0.05$, $p < 0.01$) and positively correlated with one another. Teat measurements, viz., FTL, RTL, FTD, and RTD, showed no significant correlation with milk yield, similar to those reported by Bhuiyan et al. [16], Deng et al. [36], Erdem et al. [37], Mingoas et al. [31], Patel et al. [30], Singhai et al. [38], and Yakubu [39]. The r_p observed between udder measurements across the three parities indicates that these measurements are closely interrelated and, as such, can be deemed strong explanatory variables of milk productivity compared to the rather haphazard and generally non-significant r_p involving teat measurements across the three parities. Additionally, the high r_p between udder measurements and milk yield is indicative of a probable genetic correlation. Furthermore, since studies by Byskov et al. [18], Ducro et al. [19], and Khan and Khan [20] revealed the physical traits of udder and teats in cattle to be moderately to highly heritable and highly repeatable, UL, UW, and UD are viable selection criteria for improved milk yield in White Fulani cows.

The high significance ($p < 0.01$) of Factor 1 in the principal component regression supports UL, UW, UD, FTL, and RTL as probable indicators of milk yield. Factor 2 was not significant, hence eliminating the FTD and RTD as potential indicators of milk yield. The reduced model from the stepwise regression was significant ($p < 0.01$). UL was the only trait that entered the reduced model across the three parities. Nonetheless, a positive and significant ($p < 0.05$) explanatory effect of UL on TDMY was observed across the three parities understudied, indicating that TDMY would increase as UL increases. This further strengthens the prospect of UL as a selection criterion for improved milk yield. Comparison of R^2 and R^2 (adj) values of models generated using principal component regression (R^2 = 0.472, R^2 (adj) = 0.402) and stepwise regression (R^2 = 0.491, R^2 (adj) = 0.460) for parity 2 shows that the latter is better at predicting milk yield from udder traits. The same was observed by Eyduran et al. [40], who studied the relationship between lactation milk yield (LMY), somatic cell count (SCC), and udder traits using different statistical techniques. In their study, stepwise regression had an R^2 (adj) of 59.8% and principal component regression had an R^2 (adj) of 59.2%. Additionally, the unsuitability of data corresponding to parities 3 and 4 for factor analysis further diminishes the use of principal component regression to evaluate a functional relationship between milk yield and udder morphology traits.

5. Conclusions

The study provides new insights into the relationship between udder morphology traits and milk yield in White Fulani cows. The study obtained no significant effect of parity on milk yield or udder morphology traits in White Fulani cows. The study also showed that there were significant correlations between UL, UW, UD, and TDMY. Furthermore, the regression models showed that UL and UW have the strongest relationships with TDMY. The relationship between UL and TDMY was particularly outstanding. Teat-related traits, viz., FTL, RTL, FTD, and RTD, have no marked relationship with TDMY. The results suggest a probable genetic correlation between TDMY and UL. Therefore, since udder conformation traits are heritable, when selecting for udder length, a correlated response in milk yield is expected.

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