

Milk production, milk composition and udder characteristics of West African Dwarf and Red Sokoto does assigned to different mating groups under a humid tropical production system

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ABSTRACT: Goat milk is an important source of animal protein and essential nutrients, particularly in tropical production systems. This study evaluated reproductive performance, milk production, milk composition, and udder characteristics of West African Dwarf (WAD) and Red Sokoto (RS) does assigned to four mating groups under a humid tropical production system. The foundation population comprised 88 goats: 40 WAD does, 40 RS does, four WAD bucks, and four RS bucks. The 80 foundation does were allocated to four mating groups of 20 does each: WAD × WAD, RS × RS, RS × WAD and WAD × RS. All milk-producing animals evaluated in the present study were the foundation does. The animals were managed under a semi-intensive production system for 12 months from March 2025 to February 2026. Reproductive performance, milk production, milk composition, udder dimensions and teat characteristics were recorded. Data were analysed using analysis of variance, while repeated observations during lactation were analysed using a repeated-measures approach. Significant means were separated using Duncan's Multiple Range Test at $P < 0.05$. The does in the RS × WAD and WAD × RS mating groups recorded higher average, initial, peak and total milk yields than those in the WAD × WAD and RS × RS groups. Milk fat, protein, total solids, solids-not-fat and moisture differed significantly among mating groups, whereas lactose, ash and pH did not. Udder dimensions, udder volume and teat characteristics also differed significantly among groups. Strong positive correlations were observed between several udder measurements and milk-production traits, suggesting that udder morphology may provide useful phenotypic information for evaluating milk-producing potential.

Keywords: Mating group, milk composition, milk yield, Red Sokoto goat, udder morphology, West African Dwarf goat.

INTRODUCTION

Goat milk is an important animal-derived food that provides protein, fat, lactose, minerals and other nutrients for human consumption. Its production is particularly relevant in tropical regions where goats are widely kept by smallholder farmers because of their adaptability, relatively low production requirements and ability to utilise available feed resources (Alphonsus *et al.*, 2010; Keskin *et al.*, 2016). In Nigeria, indigenous goat breeds therefore represent valuable genetic resources for livestock production and food security, particularly under locally

adapted production systems (Akpa *et al.*, 2002; Mba *et al.*, 1975; Sam *et al.*, 2017; Okon *et al.*, 2023).

Milk production in goats is influenced by genetic and environmental factors, including breed, parity, litter size, stage of lactation, nutrition and management (Sam, 2012). Differences in genetic background can affect both milk yield and milk composition. Studies involving Nigerian indigenous goats have demonstrated variation in milk yield and composition among breeds and under different production environments (Akpa *et al.*, 2002; Ahamefule *et*

al., 2017; Ishaku *et al.*, 2023). The West African Dwarf (WAD) goat is well adapted to the humid tropical environment of southern Nigeria, whereas the Red Sokoto (RS) goat is widely distributed in the northern and drier zones of Nigeria. Evaluation of these breeds under a common production environment is therefore useful for understanding their productive characteristics under humid tropical conditions.

Average daily milk yield provides an indication of routine production, while initial and peak yields provide information about production during the early and maximum phases of lactation. Total milk yield reflects cumulative production over the defined monitoring period. Lactation-curve characteristics can consequently provide useful information about the pattern and distribution of milk production during lactation (Gipson and Grossman, 1990; Nwosu *et al.*, 2022). In WAD goats, lactation characteristics have been shown to vary with factors such as parity, litter size and lactation management (Nwosu *et al.*, 2022).

Milk composition is also important when assessing the productive value of goats. The major components of goat milk include fat, protein, lactose, total solids, solids-not-fat, minerals and water. These components influence the nutritional value and processing characteristics of milk. Earlier studies involving WAD, RS and Saanen goats demonstrated variation in milk composition at different stages of lactation (Mba *et al.*, 1975). Similarly, differences in milk composition among indigenous Nigerian goats have been associated with breed, lactation stage and other production factors (Zahraddeen *et al.*, 2007; Muhammad *et al.*, 2021; Ishaku *et al.*, 2023).

Udder morphology is closely related to milk production because the udder is the organ responsible for milk synthesis, storage and secretion. Positive relationships between udder measurements and milk yield have been reported in Nigerian goats, including Red Sokoto goats (Akpa *et al.*, 2003; James and Osinowo, 2004; Sam *et al.*, 2017). Akpa *et al.* (2003), for example, reported significant relationships between udder and teat characteristics and milk yield in Red Sokoto does.

Previous studies have compared WAD and RS goats and have also examined purebred and crossbred progeny (Nwachukwu *et al.*, 2012; Ahamefule *et al.*, 2017). However, information remains limited on milk production, milk composition, and udder characteristics of foundation WAD and RS does maintained under the same humid tropical production environment while assigned to different sire-breed mating groups.

The present study therefore evaluated reproductive performance, milk production, milk composition, udder characteristics and teat characteristics of foundation WAD and RS does assigned to four mating groups: WAD × WAD, RS × RS, RS × WAD and WAD × RS. The study also examined the relationships between udder measurements and milk-production traits.

MATERIALS AND METHODS

Study area

The study was conducted at the Goat Unit of the Teaching and Research Farm, Akwa Ibom State University, Obio Akpa Campus, Akwa Ibom State, Nigeria. Obio Akpa is located within the humid tropical rainforest zone of southeastern Nigeria, between latitudes 4°30'N and 5°30'N and longitudes 7°30'E and 8°00'E. The area is characterised by a tropical monsoon climate, with annual rainfall of approximately 2,000 - 2,500 mm, mean annual temperature of 24 - 30°C and relative humidity of approximately 75 - 79% (AKSG, 2022). The study lasted 12 months, from March 2025 to February 2026.

Ethical approval

The study was conducted in accordance with recognised principles for the humane management and handling of animals used in research and education (WOAH, 2024). Adequate feed, drinking water, housing, routine health care and appropriate animal - handling procedures were provided throughout the study. Ethical approval was obtained from the Research and Ethics Committee Board of Akwa Ibom State University, Obio Akpa Campus, Akwa Ibom State, Nigeria (Approval No. AKSU - AGR - REC/2023/004).

Experimental animals and management

A total of 88 healthy adult goats constituted the foundation breeding population. The population comprised 40 WAD does, 40 RS does, four WAD bucks and four RS bucks. The foundation does were 8–12 months of age and weighed approximately 18 kg at the commencement of the breeding programme. The bucks were mature, clinically healthy and reproductively sound.

Before commencement of the breeding programme, all animals underwent a 28 - day quarantine and acclimatisation period. During this period, the goats were subjected to routine physical and clinical examinations, vaccinated against Peste des Petits Ruminants (PPR), dewormed and treated against ectoparasites using recommended veterinary procedures. Animals were subsequently monitored routinely throughout the experimental period.

The goats were housed in well - ventilated, half - walled conventional pens with concrete floors. Pens were cleaned daily and disinfected periodically to maintain hygienic conditions. Each animal was identified with a numbered ear tag for individual identification, pedigree recording and longitudinal monitoring.

The goats were managed under a semi-intensive

Table 1. Percentage composition of concentrate ration.

Feed Ingredient	%
Maize offal	50.00
Wheat offal	6.50
PKC	39.00
Bone meal	3.00
Mineral Vitamin Premix	0.25
SALT	1.25
Total	100

production system. They were allowed to graze cultivated pasture at the Teaching and Research Farm from 09:00 am to 2:00 h pm and received a concentrate supplementation (Table 1). Fresh drinking water and mineral salt were provided ad libitum throughout the study.

Experimental design and mating groups

The 80 foundation does were allocated to four mating groups of 20 does each: T1 (WAD × WAD), T2 (RS × RS), T3 (RS × WAD) and T4 (WAD × RS). The first breed designation denotes the sire breed, while the second denotes the dam breed. Thus, RS × WAD represents a WAD foundation doe assigned to an RS buck, whereas WAD × RS represents an RS foundation doe assigned to a WAD buck.

Two bucks of the appropriate breed were assigned to each mating group, giving a buck-to-doe ratio of 1:10. Mating groups were maintained separately to prevent uncontrolled mating. Does were monitored for oestrus and naturally mated within their designated groups. Sire, dam and mating dates were recorded for each animal.

Reproductive Performance

Reproductive performance was evaluated using conception rate, kidding rate, gestation length, litter size and kid birth weight, as given below in the following equations.

$$\text{Conception rate (\%)} = \frac{\text{number of pregnant does}}{\text{number of does mated}} \times 100$$

$$\text{Kidding rate (\%)} = \frac{\text{number of does that kidded}}{\text{number of does mated}} \times 100$$

$$\text{Gestation length (days)} = \text{kidding date} - \text{mating date}$$

$$\text{Litter size (kids/doe)} = \frac{\text{total number of kids born}}{\text{number of does that kidded}}$$

Kid birth weight was measured individually immediately after birth using a calibrated weighing scale.

Milk production and lactation recording

Following kidding, does were hand-milked using a uniform procedure, and milk yield was recorded daily for 120 days. Milk was weighed using a calibrated balance, and the following individual records were maintained:

- Initial milk yield was the first daily yield recorded.
- Peak milk yield was the highest daily yield recorded during the monitoring period and was identified as: Peak milk yield = maximum daily milk yield.
- Time to peak yield was calculated as: Time to peak (days) = date of peak yield – kidding date.
- Total milk yield was calculated as: Total milk yield (kg) = Σ daily milk yields. Because milk production was monitored for a defined 120-day period, total milk yield represents cumulative production during the specified monitoring period
- Lactation length was defined as the number of days from kidding to the final day on which milk yield was recorded before the doe ceased lactating.
- Lactation persistency was not statistically estimated because a persistency coefficient was not calculated in the present study.

Milk sampling and quality analysis

Representative milk samples were collected aseptically from individual does at predetermined sampling periods. Each sample was placed in a clean, labelled container and refrigerated until laboratory analysis. Fat, protein, lactose, total solids, solids - not - fat, ash, moisture and pH were determined using standard laboratory procedures.

Total solids were calculated as: Total solids (%) = 100 – moisture (%).

Solids - not - fat was calculated as: SNF (%) = total solids (%) – fat (%).

Moisture was calculated as: Moisture (%) = 100 – total solids (%).

Milk pH was measured directly using a calibrated pH meter.

Udder and teat measurements

Udder and teat characteristics were measured during lactation at approximately the same time of day to minimise variation associated with udder filling. Udder length, width, depth and circumference were measured in centimetres using a flexible measuring tape at standardised anatomical points. Udder volume was determined using the adopted udder-volume estimation procedure and expressed in litres. Teat length was

measured from the base to the tip of the teat using a ruler or measuring device, while teat diameter was measured at a standardised point using a vernier or digital calliper. All measurements were recorded for the individual doe.

Data collection

Individual animal records were maintained throughout the study. The records included animal identification number, breed, mating group, sire, dam, birth date, birth weight, sex, litter size, mating date, kidding date, gestation length, daily milk yield, milk composition values and udder and teat measurements.

Statistical analysis

Data were analysed using SPSS Statistics Version 25.0 (IBM Corp., 2025). Analysis of variance was used to evaluate differences among mating groups for reproductive performance, milk-production traits, milk composition, udder characteristics and teat characteristics. For traits analysed as single observations, the general statistical model was:

$$Y_{ij} = \mu + M_i + e_{ij}$$

Where: Y_{ij} = observed value of the trait, μ = overall mean, M_i = fixed effect of mating group; and e_{ij} = random residual error.

The four mating groups were WAD × WAD, RS × RS, RS × WAD and WAD × RS.

Milk-yield observations collected repeatedly during lactation were analysed using a repeated-measures approach, with the individual doe treated as the subject to account for the dependence among repeated observations from the same animal. Where applicable, sire was considered as a random effect. The analysis accounted for the repeated nature of milk-yield observations rather than treating all daily observations from the same doe as independent observations.

Significant group means were separated using Duncan's Multiple Range Test (DMRT) at the 5% probability level ($p < 0.05$). Pearson's correlation analysis was used to determine the relationships between milk-production traits and udder/teat characteristics. Correlation coefficients were presented as a heat map to facilitate visualisation of the direction and magnitude of associations.

RESULTS AND DISCUSSION

Reproductive performance and kid birth weight

Table 2 showed the results of the effect of Mating group on reproductive performance and birth weight of kids. Conception rate differed significantly ($p < 0.05$) among the

mating groups, with the highest values recorded in RS × WAD (84.62%) and WAD × RS (83.33%), compared with 80.00% in WAD × WAD. The RS × RS group (82.08%) was intermediate. The higher conception rates observed in the two reciprocal mating groups may reflect differences among the mating assignments; however, the present experiment did not directly quantify heterosis or establish a specific genetic mechanism responsible for these differences. The values were slightly lower than the 87.1% reported for WAD goats by Abdul-Rahman (2017), possibly because of differences in management, breeding season and experimental population.

Kidding rate, gestation length and litter size were not significantly affected ($p > 0.05$) by mating group. Kidding rate ranged from 72.00 to 76.00%, while gestation length ranged from 150 to 153 days. These gestation values fall within the normal range expected for goats and indicate little reproductive effect of genotype under the conditions of the present study. Litter size ranged from 1.66 to 1.80 kids/doe, comparable with the 1.6 ± 0.5 reported for WAD goats by Adeoye (1985). Differences among studies may arise from differences in doe age, nutrition, season and management, since these factors can influence reproductive traits.

Birth weight was significantly affected ($P < 0.001$), with RS × RS recording the highest value (1.84 kg), followed by WAD × RS (1.74 kg) and RS × WAD (1.73 kg), while WAD × WAD had the lowest (1.41 kg). The differences may reflect variation in dam breed, sire breed and other maternal or litter-related factors. Nwachukwu *et al.* (2012) similarly reported genotype-related differences in performance between pure and crossbred progeny of RS and WAD goats.

Average daily milk yield

Figure 1 showed a Simple Bar of average milk yield. Results revealed that average daily milk yield was 0.45, 0.46, 0.50 and 0.50 kg/day for WAD × WAD, RS × RS, RS × WAD and WAD × RS, respectively. The reciprocal mating groups recorded numerically higher average daily milk yield than the two same-breed mating groups. The observed pattern may be associated with differences in the breed composition of the foundation dams, individual variation and other factors affecting lactation. Milk yield is known to be influenced by parity, litter size, stage of lactation, nutrition and management (Akpa *et al.*, 2002; Nwosu *et al.*, 2022). Serradilla (2001) noted that responses to crossbreeding in dairy goats depend strongly on parental genetic merit and production environment. Such crossbreeding effects cannot, however, be directly inferred from the present foundation-dam observations.

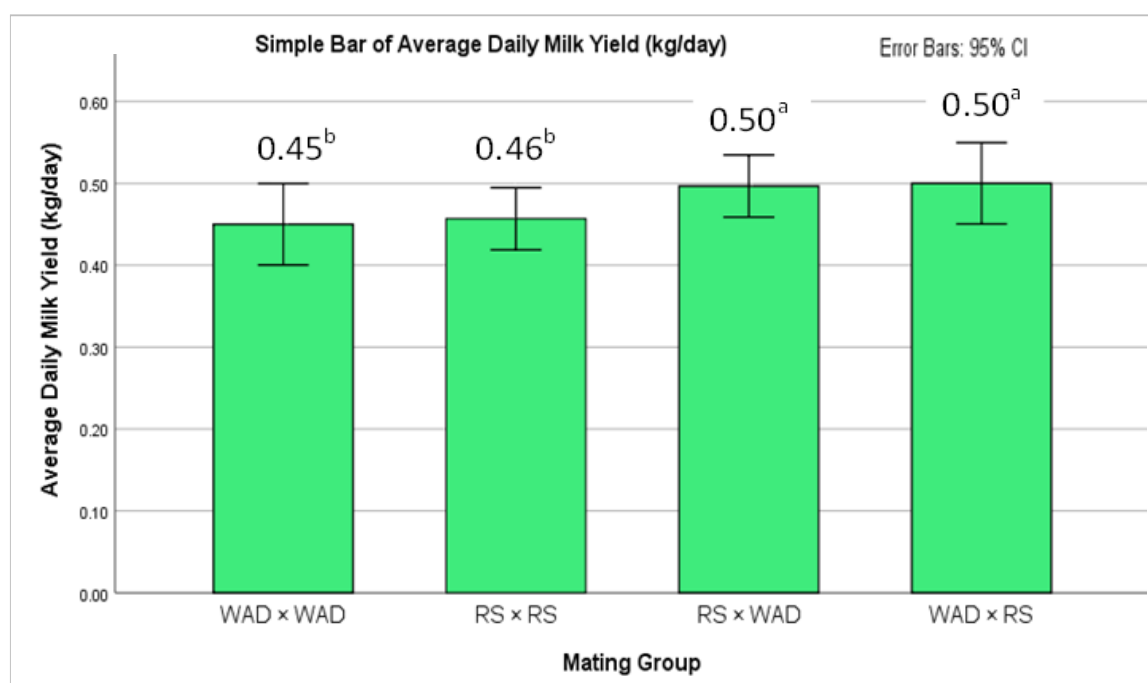
Initial milk yield

Figure 2 presents initial milk yield. Initial milk yield was 0.39, 0.45, 0.58 and 0.50 kg/day for WAD × WAD, RS ×

Table 2. Reproductive performance and kid birth weight of foundation does according to mating group.

Traits	WAD X WAD	RS X RS	RS X WAD	WAD X RS	SEM	p - value
Conception rate (%)	80.00 ^b	82.08 ^{ab}	84.62 ^a	83.33 ^a	0.65	0.039
Kidding rate (%)	74.00	72.00	73.00	76.00	0.82	0.394
Gestation length (days)	150.00	151.00	153.00	151.00	0.58	0.217
Litter Size (Kids /Doe)	1.72	1.66	1.80	1.75	0.03	0.247
Birth weight (kg)	1.41 ^b	1.84 ^a	1.73 ^a	1.74 ^a	0.05	0.001

WAD = West African Dwarf; RS = Red Sokoto; SEM = standard error of the mean. Means within a row bearing different superscripts differ significantly ($p < 0.05$).

**Figure 1.** Mean average daily milk yield of foundation does assigned to the four mating groups.

RS, RS x WAD and WAD x RS, respectively. Initial milk yield differed significantly ($P < 0.05$) among the mating groups, with the highest observed value occurring among WAD foundation does assigned to RS bucks (RS x WAD), followed by RS foundation does assigned to WAD bucks (WAD x RS). The lowest value occurred in WAD x WAD. The observed differences indicate variation in initial milk production among the foundation does in the respective mating groups. Akpa *et al.* (2002) reported substantial variation in milk-yield characteristics of RS does and showed that factors including herd, season, parity and litter size influenced milk production.

Peak milk yield

Figure 3 shows peak milk yield. Significant differences ($p < 0.05$) were observed among mating groups. Peak milk yields were 0.60, 0.70, 0.80 and 0.80 kg/day for WAD x

WAD, RS x RS, RS x WAD and WAD x RS, respectively. The two reciprocal mating groups recorded the highest observed peak milk yields, whereas WAD x WAD recorded the lowest. The results indicate higher observed maximum milk production among the foundation does in the reciprocal mating groups during the defined lactation-monitoring period. Peak milk yield is influenced by mammary development, nutrient availability, stage of lactation and other physiological and management factors. Ahamefule *et al.* (2017) reported significant effects of breed and stage of lactation on milk production in WAD and RS goats maintained under hot-humid conditions.

Total milk yield

Total milk yield results are shown in Figure 4. The results revealed that Total milk yield was 47.26 kg for WAD x WAD, 50.38 kg for RS x RS, 55.04 kg for RS x WAD and

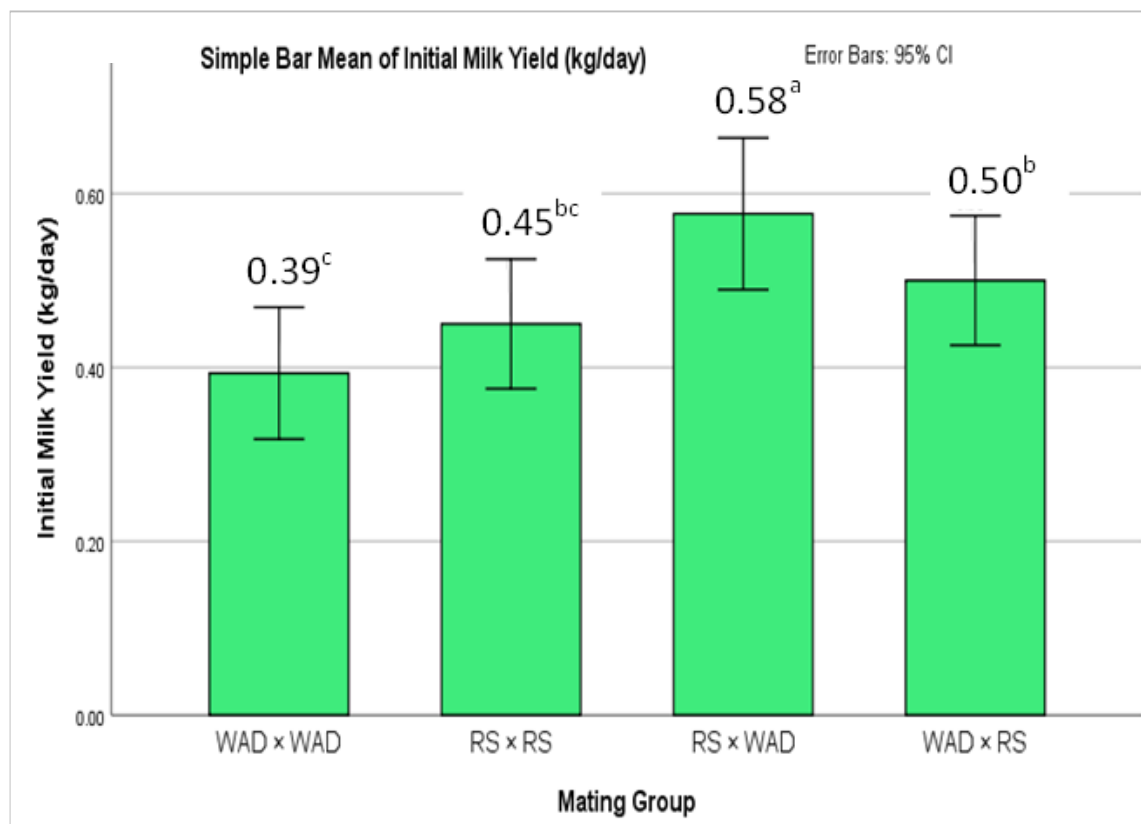


Figure 2. Mean initial milk yield of foundation does assigned to the four mating groups.

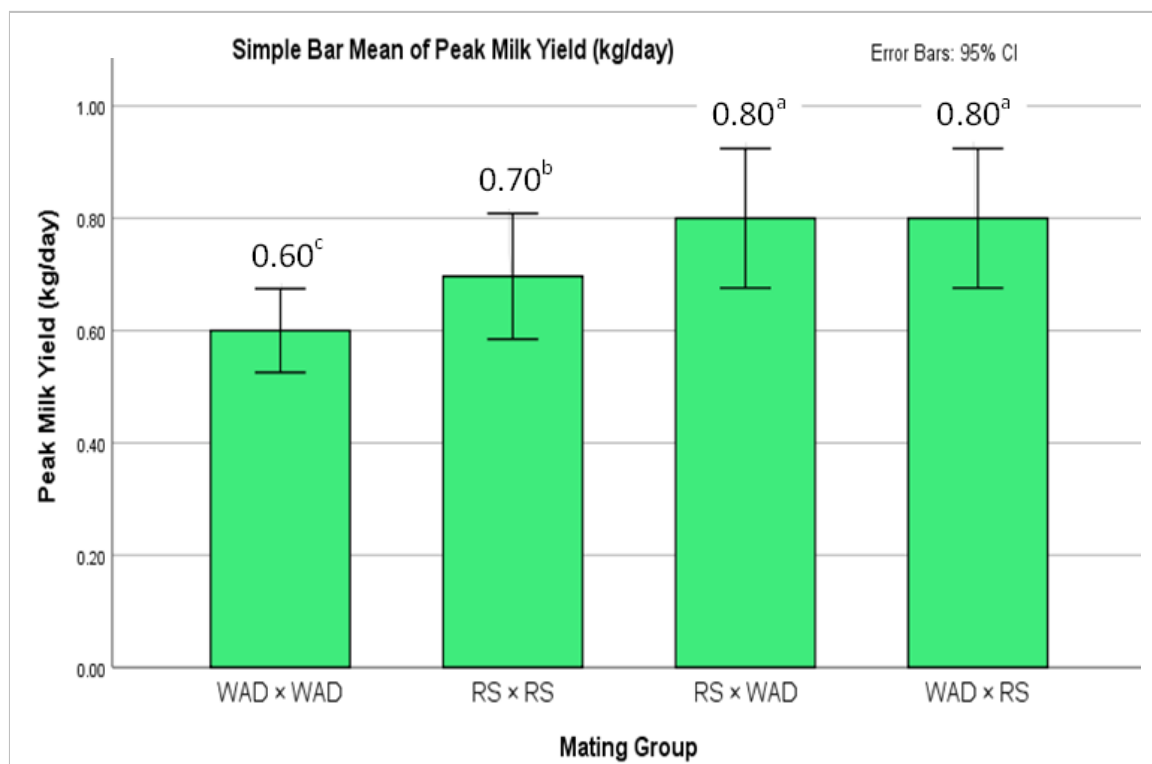


Figure 3. Mean peak milk yield of foundation does assigned to the four mating groups.

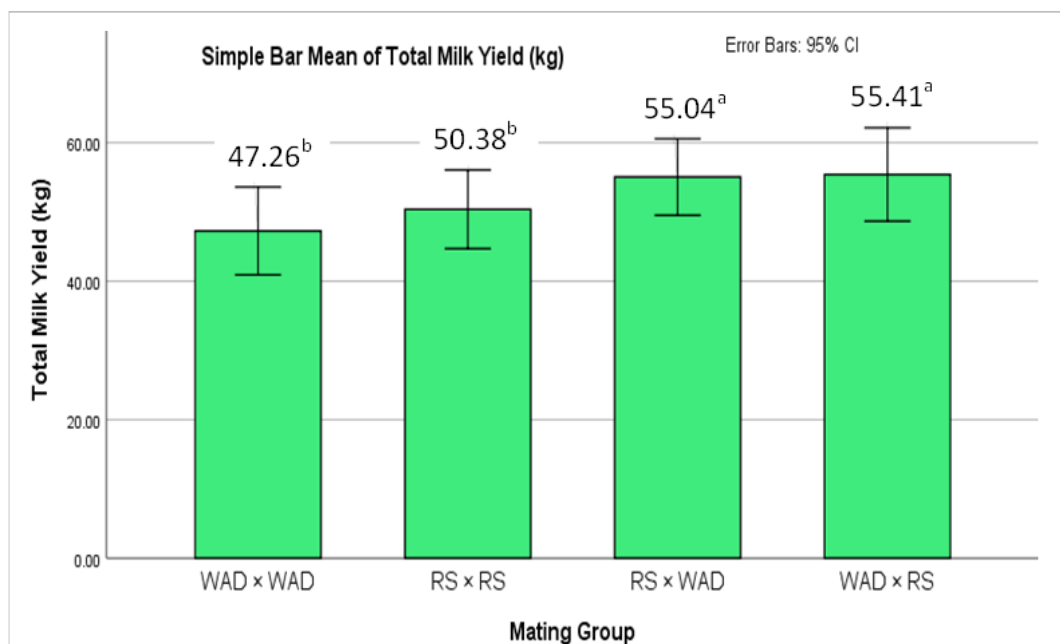


Figure 4. Mean total milk yield of foundation does during the defined 120-day monitoring period according to mating group.

Table 3. Milk composition and physicochemical characteristics of foundation does according to mating group.

Parameters	WAD X WAD	RS X RS	RS X WAD	WAD X RS	SEM	P - value
Milk fat (%)	4.05 ^b	3.00 ^c	4.50 ^a	4.00 ^b	0.17	0.000
Milk protein (%)	4.00 ^a	3.80 ^b	4.00 ^a	4.00 ^a	0.03	0.002
Lactose (%)	4.30	4.30	4.40	4.40	0.02	0.052
Total solids (%)	15.00	11.00	14.50	14.50	0.48	0.000
SNF (%)	10.95 ^a	8.00 ^d	10.02 ^c	10.50 ^b	0.34	0.000
Ash (%)	0.65	0.65	0.65	0.65	0.00	1.000
Moisture	85.00 ^c	89.00 ^a	85.50 ^b	85.5 ^b	0.07	0.000
Milk pH	6.40	6.40	6.40	6.40	0.00	1.000

WAD = West African Dwarf; RS = Red Sokoto; SNF = solids-not-fat; SEM = standard error of the mean. Means within a row bearing different superscripts differ significantly ($p < 0.05$). Total solids and SNF were calculated variables.

55.41 kg for WAD × RS, and differed significantly ($p < 0.05$) among the mating groups. The greater cumulative yield of the crossbred does is consistent with their higher daily and peak yields. Akpa *et al.* (2002) reported substantially higher total yield in agropastoral RS goats, but their animals were evaluated under a different production system and over a longer observational framework. Such differences in management, season, parity, litter size and lactation recording can account for differences in absolute milk yield between studies. Nwosu *et al.* (2022) also reported that lactation - curve parameters in WAD goats are affected by parity, litter size and oxytocin treatment, demonstrating that non - genetic factors can alter the expression of lactational performance. Differences between their findings and the present milk - yield pattern may therefore reflect the trait measured, age or sex

structure, management, location and the specific parental animals used.

Milk composition and physicochemical characteristics

The effect of mating group on milk composition and physicochemical characteristics is shown in Table 3. Results showed that milk fat differed significantly ($P < 0.001$), ranging from 3.00% in RS × RS to 4.50% in RS × WAD. Protein also differed significantly, with WAD × WAD, RS × WAD and WAD × RS recording 4.00%, compared with 3.80% in RS × RS.

The higher fat concentration observed in the RS × WAD group indicates a higher measured milk-fat concentration among the foundation does assigned to this mating group.

Table 4. Udder and teat characteristics of foundation does according to mating group.

Traits	WAD X WAD	RS X RS	RS X WAD	WAD X RS	SEM	p-value
Udder length (cm)	10.50 ^d	12.40 ^c	14.20 ^a	13.60 ^b	0.43	0.000
Udder width (cm)	8.80 ^b	9.06 ^b	10.12 ^a	10.11 ^a	0.19	0.000
Udder depth (cm)	7.00 ^c	8.00 ^b	9.20 ^a	9.10 ^a	0.28	0.000
Udder circumference (cm)	22.00 ^c	24.00 ^b	25.20 ^a	24.50 ^{ab}	0.38	0.000
Udder Volume (L)	0.35 ^c	0.45 ^b	0.52 ^a	0.56 ^a	0.02	0.000
Teat length (cm)	2.50 ^b	2.63 ^{ab}	2.80 ^a	2.62 ^{ab}	0.04	0.000
Teat diameter (cm)	1.80 ^a	1.60 ^b	1.58 ^b	1.53 ^b	0.03	0.00

WAD = West African Dwarf; RS= Red Sokoto; SEM = Standard Error of the Mean; ^{a,b,c} mean in a row with different superscripts are significantly different ($p < 0.05$).

Breed and lactation effects on milk fat and protein have been reported in Nigerian indigenous goats (Mba *et al.*, 1975; Zahraddeen *et al.*, 2007; Ishaku *et al.*, 2023).

Lactose did not differ significantly ($P=0.052$), although numerical differences occurred among the groups. This indicates that lactose concentration was relatively stable across the mating groups under the conditions of the study, supporting the view that lactose is less responsive to breed differences than some other milk components. In contrast, previous studies have reported significant effects of breed and stage of lactation on lactose concentration, demonstrating that feeding, lactation stage and production environment can influence its expression (Mba *et al.*, 1975; Zahraddeen *et al.*, 2007).

Moisture showed the reverse pattern, with the highest value occurring in RS $\times$ RS (89.00%). Ash and pH were identical across the four groups, with values of 0.65% and 6.40, respectively, and were not significantly affected. The stability of pH is consistent with observations that milk pH can be relatively stable across breed and lactation conditions (Zahraddeen *et al.*, 2007).

Udder and teat characteristics

Table 4 presents the udder and teat characteristics of the foundation does. All measured udder traits differed significantly ($p < 0.001$) among mating groups. Udder length was 10.50, 12.40, 14.20 and 13.60 cm for WAD $\times$ WAD, RS $\times$ RS, RS $\times$ WAD and WAD $\times$ RS, respectively. Udder width ranged from 8.80 to 10.12 cm, while udder depth ranged from 7.00 to 9.20 cm. The reciprocal mating groups generally recorded larger udder dimensions than WAD $\times$ WAD. Udder circumference ranged from 22.00 cm in WAD $\times$ WAD to 25.20 cm in RS $\times$ WAD. Udder volume was 0.35, 0.45, 0.52 and 0.56 L for WAD $\times$ WAD, RS $\times$ RS, RS $\times$ WAD and WAD $\times$ RS, respectively. The larger measured udder dimensions observed in the reciprocal mating groups indicate differences in udder morphology among the foundation does assigned to the mating groups. These differences may be associated with differences in breed background, individual variation, lactation stage and management.

Positive relationships between udder dimensions and milk yield have been reported in WAD, RS and other goat populations (Akpa *et al.*, 2003; James and Osinowo, 2004; Sam *et al.*, 2017). Capote *et al.* (2006) similarly demonstrated associations between udder morphology, milk yield and milking ability in dairy goats.

Teat length was highest in RS $\times$ WAD (2.80 cm), while teat diameter was highest in WAD $\times$ WAD (1.80 cm). The differences indicate variation in teat morphology among the foundation does. However, greater teat dimensions do not necessarily imply superior milking ability or udder health. Udder and teat morphology are influenced by genetic and environmental factors, lactation number and season (Mavrogenis *et al.*, 1989; McLaren *et al.*, 2016; Vrdoljak *et al.*, 2020).

Correlation between milk-production traits and udder characteristics

Figure 5 presents the correlation heat map between milk-production traits and udder characteristics. Strong positive associations were observed between several udder measurements and milk-production traits. Average daily milk yield was positively correlated with udder length ($r=0.818$), udder width ($r=0.940$), udder depth ($r=0.899$), udder circumference ($r=0.818$), udder volume ($r=0.886$) and teat length ($r=0.768$). Initial and peak milk yields also showed strong positive associations with several udder measurements. Peak milk yield showed its strongest reported correlation with udder depth ($r=0.976$). Total milk yield was strongly positively correlated with udder width ($r=0.940$), udder depth ($r=0.947$), udder circumference ($r=0.903$), udder volume ($r=0.940$) and teat length ($r=0.811$). Lactation length was also positively associated with several udder measurements, with the strongest reported relationship occurring with udder circumference ($r=0.953$).

These associations are consistent with previous reports that udder dimensions can be useful phenotypic indicators of milk-producing capacity in goats (Akpa *et al.*, 2003; James and Osinowo, 2004; Sam *et al.*, 2017; Williams *et al.*, 2019). However, the magnitude of the correlations

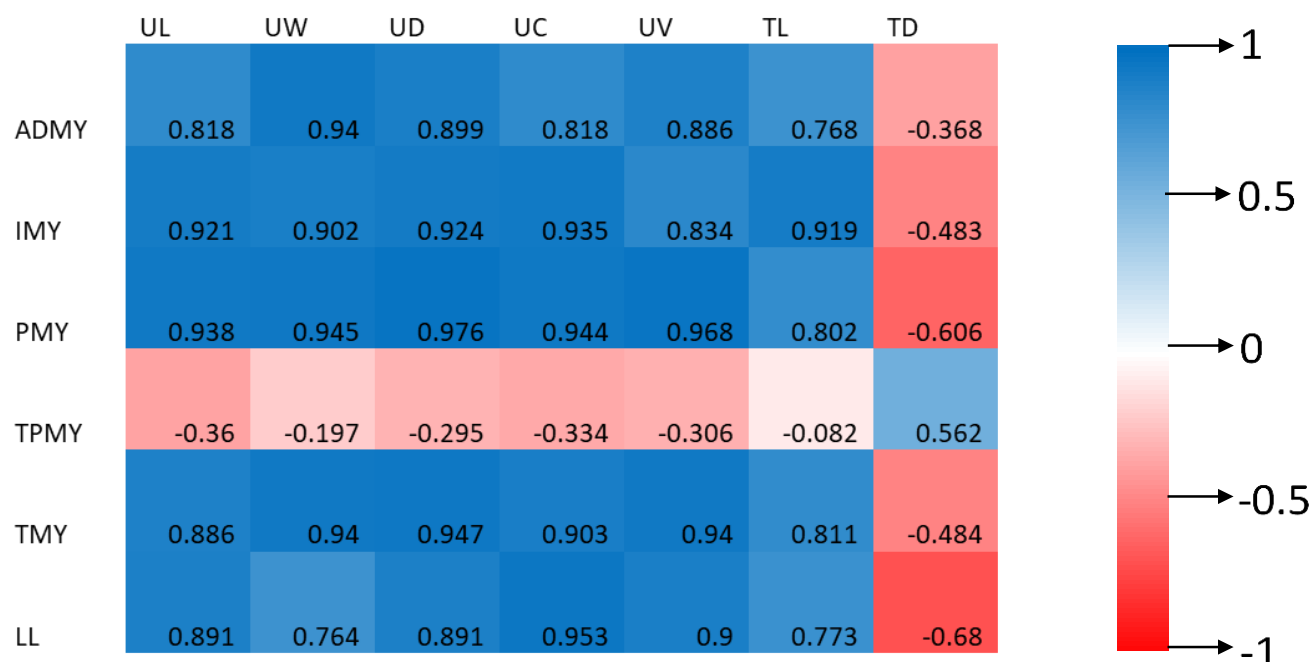


Figure 5. Pearson correlation heat map showing the associations between milk-production traits and udder and teat characteristics of foundation does.

observed in the present study was greater than that reported in some previous studies. The strong correlations should therefore be interpreted cautiously. Akpa *et al.* (2003) reported positive relationships between udder and teat measurements and milk yield in Red Sokoto goats, although their correlation coefficients were generally lower than several values observed in the present study.

Conclusion

The foundation WAD and RS does assigned to the four mating groups differed in several reproductive, milk-production, milk-composition and udder characteristics under the humid tropical production conditions of the study. The reciprocal mating groups recorded higher observed average, initial, peak and total milk yields than the same-breed mating groups, while several udder dimensions were also greater in these groups.

Milk fat, protein, total solids, SNF and moisture differed among the groups, whereas lactose, ash and pH were relatively stable. Strong positive associations were observed between several udder measurements and milk-production traits, suggesting that udder morphology may provide useful phenotypic information for evaluating milk-producing potential.

CONFLICT OF INTEREST

The author declares that they have no conflict of interest.

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