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Heterosis of Linear Body Traits in Crossbred Cattle Reared in the Humid Rainforest Zone of Nigeria

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Target Audience: Cattle farmers, Animal Scientists, cattle breeders, policy makers

Abstract

This study evaluated the heterosis of linear body traits at various growth phases in F_1 crossbred cattle namely BOxND, BOxWF, GUxWF, NDxMU, NDxWF, and WFxMU relative to the average of purebred generation. Muturu (MU) and N'dama (ND) were the reference breeds in the crossbreeding programme. 1,724 linear body trait data (sexes combined) at weaning, yearling, grower, and adult stages were analyzed. Significantly ($P < 0.000$) higher linear body trait values were observed in Sokoto Gudali (GU), and Red Bororo (BO) compared to MU, ND, and White Fulani (WF) across the growth phases while GUxWF and BOxWF were superior ($P < 0.000$) to other hybrids. Mean heterosis were non-significant ($P > 0.05$) but positive (except at grower phase) for HL; positive but significant only at weaning for BL; positive but significant only at yearling and grower phases for CG; and positive but significant at weaning, yearling, and grower phases for HW. Heterosis relative to the better parent in each cross were essentially negative, but generally positive relative to the inferior parent. Heterosis relative to the mean of parental breeds at weaning, yearling, grower, and adult phases was 2.54, 2.66, - 0.67, and 3.58 %, respectively for HL; 5.70, 9.08, 8.06, and 3.61 %, respectively for BL; 1.86, 5.40, 0.18, and 1.36 %, respectively for CG; and 7.57, 5.46, 5.76, and 3.88 %, respectively for HW. In conclusion, crossbreeding can be used to improve the growth and linear body traits of trypanotolerant ND, and MU cattle breeds.

Keywords: *linear body traits, crossbreeding, indigenous cattle, F_1 hybrids, heterosis.*

1. Description of problem

Conformation traits refer to the physical characteristics and structural qualities of animals such as cattle. These traits are evaluated to enhance animal welfare, productivity, and product quality (1, 2). Conformation traits evolve with animal growth; some traits being more important at specific stages of growth. During early life stage, birth weight, body length, chest girth, shoulder width and leg structure are the primary conformation traits in beef cattle (3, 4). Calves with higher birth weights, chest girth, shoulder width, and strong legs have better future growth potential, muscular development, and body balance. The study by (5) identified hip height and back length as crucial indicators of future athletic performance in horses, while (6) highlighted the importance of skeletal structure in cattle for optimal weight-bearing and efficient muscle development. In adult cattle, conformation traits play significant roles in the health, performance, and reproductive capacity of the animals. Chest girth, withers height, body length, and hip height indicate frame size, and longevity (7). Generally, the change in conformation traits with age, and their impact on animal performance and welfare is of high scientific and economic interests (8).

Conformation traits have strong genetic basis (9). They are also influenced by environmental factors such as nutrition (10). Selective breeding plays a crucial role in shaping these traits over generations. Linear body measures give objective assessment of animal performance, and in association with body weight, determines the most productive animals including cattle.

Nigerian indigenous breeds of cattle include Muturu, N'Dama, Sokoto Gudali, Red Bororo or Rahaji, and White Fulani or Bunaji (11). These cattle breeds have evolved characteristics that shaped their adaptation, survival and productivity in their native environments (12-14). Characterization of Nigerian indigenous cattle breeds based on body morphometry has been undertaken by several studies (15-17). The **Muturu** (*Bos indicus*) also known as the West African dwarf short horn are small, blocky or compact bodied, and humpless. They have broad head, straight back, short limbs, and very short horns (18). Muturu cattle are raised for meat (19). They mature early, are very fertile, and have shorter calving interval compared to the zebu breeds (20-22). Additionally, the Muturu breed is known to be more resistant to trypanosomiasis than the zebu breeds (23). Improving the growth performance of Muturu cattle in Nigeria will therefore, positively impact beef production, and encourage inclusion of the breed in cattle genetic improvement programmes (24). **The White Fulani** or Bunaji is a zebu breed that is indigenous to Northern Nigeria, Southern Niger and Northern Cameroon (25). The breed is the most numerous and widespread of all Nigerian cattle breeds (18) and represents about half (50 %) of the national herd. The animals are hardy, heat tolerant, and adapt well to local conditions (26). It has tall and narrow body, white coat, long and lyre-shaped horns, and is considered a dual-purpose (beef and milk) breed (27). Birth weight ranges from 18 to 24 kg while mature weight ranges from 250 to 650 kg depending on sex, age, management system, and production environment (23). **The Gudali (Sokoto, and Adamawa Gudali)** represents about 32% of the national herd and is regarded as the second largest cattle breed in Nigeria (28). The Gudali is characterized by well-developed dewlap, pendulous ears, very short horn or hornless (polled), and cream, or light-gray to grayish-brown coat (18). The udders are well developed; milk yield is higher (about 1,500 kg per lactation) than in White Fulani (26, 29), and the breed is regarded as an indigenous dairy breed. Mature weight ranges from 330 to 450 kg.

Red Bororo or Rahaji is the third largest cattle breed in Nigeria, representing about 22% of the national herd (28). It is adapted to the arid and semi-arid regions. The Rahaji is one of the largest zebu breeds and is distinguished by its deep burgundy-colored coat, pendulous ears and long, thick horns (30, 31). Fulani pastoralists consider the Rahaji a prestigious breed, and mostly use the animals for crossbreeding. The breed is however, susceptible to high humidity-related diseases, and poor nutrition (32). N'Dama cattle are native to Senegambia and adjacent parts of West Africa (33). They were first brought into Nigeria from Guinea in 1939 on an experimental basis. The N'Dama is a medium-sized breed with compact body and lyre-shaped, black-tipped horns and no hump (18). There is a small dewlap in the male. Coat colour include light brown, black, and pied. N'Dama is regarded as the reference trypanotolerant cattle breed (14, 21, 34).

Crossbreeding indigenous cattle genotypes is a common practice worldwide to enhance desirable traits, such as disease resistance, growth rate, and milk yield (35, 36). Crossbreeding also contributes to genetic diversity and conservation efforts by creating diverse gene pools (37). It enables the exploitation of breed strengths through breed complementarity, and heterosis. Heterosis is the difference in mean phenotypic values of crossbreds and their purebred parents (38). It results from non-additive genetic effects. Heterosis has been demonstrated for fertility, lactation yield, and growth traits in different animal species (39-41). The expression of heterosis depends on breed combination, trait type, and production environment. The exploitation of heterosis is the most important reason for utilizing crossbreeding in livestock production. There is the possibility that hybrids of indigenous zebu and taurine cattle breeds would manifest hybrid vigour or heterosis in growth performance expressed in improved linear body traits. The present study was hence designed to evaluate the heterosis of linear body traits in F_1 crossbred indigenous cattle in a humid rainforest zone.

2. Materials and methods

2.1 Location of study

The study was carried out at the cattle breeding unit of the Livestock Teaching and Research Farm, Michael Okpara University of Agriculture Umudike Abia State, Nigeria (latitude 05° 29' North, and longitude 07° 32' East; ambient temperature range: 25 to 35°C; annual rainfall range: 1677.5 to 2200 mm) (42).

2.2 Herd structure and breeding management

The cattle herd comprised of purebreeds namely N'dama (ND), Sokoto Gudali (GU), Red Bororo (BO), and White Fulani (WF), and various crossbred genotypes. The herd was managed semi-intensively with daily grazing of natural pasture, and supplemental feeding and watering in the holding area. The animals were identified with ear-tag numbers. Bulls were housed and grazed together with cows however, farm record showed that most calving events occurred during April to December.

2.3 Experimental animals and measurement of linear body traits

Animals whose records were used for the study were BO, GU, ND, WF, and MU; and crossbred genotypes: BOxND, BOxWF, GUxWF, NDxMU, NDxWF, and WFxMU. Measurement of linear body traits namely head length (HL), body length (BL), chest girth (CG), and height at withers (HW) were performed on ND (n = 6), GU (n = 4), and WF (n = 8); BOxND (n = 3), BOxWF (n = 2), NDxWF (n = 3), NDxMU (n = 2), GUxWF (n = 4), and WFxMU (n = 5) belonging to different growth phases. In addition, age-linear body trait data belonging to BO, GU, ND, WF, and MU; BOxND, BOxWF, GUxWF, NDxMU, NDxWF, and WFxMU were extracted from the herd record and used for the study. According to herd record, linear body traits were recorded at weaning (6-11), yearling (12-24), grower (25-36), and adult (> 36) months of age (moa). Head length (HL) was measured as the distance from the nape to the rostral end of muzzle. Body length (BL) was measured as the distance from the point of shoulder to the pin bone (tuber ischium). Chest girth (CG) was measured as the circumference of the chest (thorax) just behind the fore legs while height at withers (HW) was the distance from the base of front leg to the highest point of withers with the animal standing erect on a level ground (7). All linear body measurements were performed using a flexible measuring tape except for HW which was measured with a measuring stick. The measuring tape and stick were calibrated in centimeters. Altogether, 223 HL, 261 BL, 258 CG, and 258 HW records belonging to purebred; and 174 HL, 184 BL, 183 CG, and 183 HW records belonging to F_1 crossbred genotypes (sexes combined) were analyzed in the study. Table 1 presents the distribution of body weight and linear body trait records at various growth stages according to genotype.

Table 1: Distribution of body weight and linear body trait records (sexes combined) according to growth stages and genetic group

	Growth stage			
Trait/genetic group	**Weaning**	**Yearling**	**Grower**	**Adult**
Head length (HL)				
Purebred	35	52	68	68
Crossbred	48	42	42	42
Body length (BL)				
Purebred	44	64	73	80
Crossbred	51	45	44	44
Chest girth (CG)				
Purebred	44	64	72	78
Crossbred	50	45	44	44
Height at withers (HW)				
Purebred	44	64	72	78
Crossbred	50	45	44	44

1.1 Statistical Analysis

Within each generation and growth stage, the effects of animal breed group and birth year on each linear body trait were analyzed using the univariate analysis of variance (UNIANOVA) in SPSS version 20.0 for windows based on the following statistical model:

$$\chi_{ijk} = \mu + G_i + \gamma_j + \Sigma_{ijk}$$

Where, χijk is an observation on the k^{th} cattle born in the j^{th} year and belonging to the i^{th} breed group (purebreds or F_1), μ is overall mean, *Gi* is the fixed effect of the i^{th} breed group, *Yj* is the fixed effect of the j^{th} year of birth and *Σijk* is random error assumed to be normally and independently distributed. Analysis showed non-significant effect of year of birth which was then removed from the model leaving the statistical model as:

$$\chi_{ijk} = \mu + G_i + \Sigma_{ijk}$$

Comparison between purebred (G_0) and each of the F_1 crossbred (G_1) for each linear body trait at each growth stage was performed using the student's t-test in SPSS version 20.0 for Windows. Heterosis of linear body traits in crossbred generation relative to purebred (G_0) generation was calculated according to (43):

$$Heterosis\ (\%) = \left(\frac{Crossbred\ average}{Purebred\ average} - 1\right) x\ 100$$

To obtain the heterosis of linear body traits for each crossbred genotype relative to the performance of each purebred parent, the expression by (43) was used:

$$Relative\ heterosis\ (\%) = \left(\frac{Crossbred\ performance}{Purebred\ performance} - 1\right) x\ 100$$

For all the analysis, heterosis for a trait was considered significant if comparison between purebred and crossbred performances in a trait showed significant difference at $P \leq 0.05$ (44).

1. Results

1.1 Effect of cattle genotype and generation on head length

Table 2 presents observed head lengths (HL) obtained at various growth stages (weaning, yearling, grower, and adult) for different cattle genotypes belonging to purebred (G_0), and crossbred (G_1).

Table 2: Head length (cm) at various growth phases for cattle purebred and crossbred cattle

Genetic group	Weaning	Yearling	Grower	Adult
Purebred cattle (G_0)				
BO	31.0 ± 0.50^{b}	40.2 ± 0.48^{a}	43.7 ± 0.47^{a}	50.1 ± 0.65^{a}
GU	32.6 ± 0.50	40.5 ± 0.49	44.3 ± 0.48	51.5 ± 0.62
MU	24.1 ± 0.50^{ea}	30.2 ± 0.48^{ca}	34.9 ± 0.47^{ca}	36.7 ± 0.64^{a}
ND	27.6 ± 0.50^{d}	31.8 ± 0.48^{b}	40.2 ± 0.47^{b}	42.3 ± 0.61^{cd}
WF	29.0 ± 0.50^{c}	31.7 ± 0.49^{b}	42.9 ± 0.48^{a}	45.1 ± 0.64^{b}
P-value	0.000	0.000	0.000	0.000
Mean G_0	28.9 ± 0.30	34.9 ± 0.38	41.1 ± 0.31	45.1 ± 0.43
Crossbred cattle (G_1)				
BOxND	29.5 ± 0.57^{b}	34.0 ± 0.55^{b}	41.7 ± 0.44^{b}	47.9 ± 0.48^{b}
BOxWF	30.6 ± 0.57^{b}	39.8 ± 0.54^{a}	43.1 ± 0.42^{a}	51.0 ± 0.48^{a}
GUxWF	32.2 ± 0.57^{a}	38.9 ± 0.54^{a}	41.3 ± 0.42^{b}	51.8 ± 0.48^{a}
NDxMU	23.0 ± 0.57^{c}	30.3 ± 0.55^{d}	38.1 ± 0.45^{d}	40.7 ± 0.48^{d}
NDxWF	30.5 ± 0.57^{b}	31.1 ± 0.54^{cd}	40.5 ± 0.42^{c}	41.5 ± 0.48^{cd}
WFxMU	29.1 ± 0.57^{b}	32.3 ± 0.54^{c}	39.9 ± 0.43^{c}	42.5 ± 0.48^{c}
P-value	0.000	0.000	0.000	0.000
Mean G_1	29.1 ± 0.28	34.4 ± 0.35	40.8 ± 0.29	45.9 ± 0.39

a,b,c,d: within generations, means on the sa me column with different lower case superscripts are significantly different (p = 0.05).

For purebred genotypes, GU recorded the highest HL across the four growth stages ($p < 0.000$) followed by BO. However, the difference between the two breeds was insignificant ($P > 0.05$) except at weaning. MU on the other hand, recorded the lowest significantly ($P < 0.000$) different HL across the growth stages. Among crossbred (G_1) genotypes, GUxWF and BOxWF dominated the first and second highest HL across all growth stages except at grower stage when BOxND recorded the second highest value for the trait. GUxWF recorded a significantly ($P < 0.000$) higher value for HL at weaning followed by BOxWF, BOxND, NDxWF, and WFxMU whose values were not significantly different ($P > 0.05$). At yearling and adult stages, GUxWF and BOxWF recorded the highest ($P < 0.000$) HL followed by BOxND and these differed significantly ($P < 0.000$) from values recorded for other crossbred genotypes. At grower stage, BOxWF had highest HL followed by GUxWF which had statistically similar value with BOxND ($P > 0.05$). Meanwhile, NDxMU recorded the lowest HL ($P < 0.000$) across the growth stages. Table 2 also presents the comparative mean HL for purebred (G_0), and crossbred (G_1) generations across the growth phases. The Table shows that purebred, and F_1 hybrid generations did not differ significantly in HL across the growth stages ($P > 0.05$).

3.2 Heterosis of head length in crossbred cattle

Table 3 presents the individual and mean heterosis of HL for G_1 generation relative to mean of parental generation, and individual parent performance. G_1 crossbreds exhibited moderate positive heterosis for HL at weaning (2.54%), yearling (2.66%), and adult (3.58%) stages, although not statistically significant. At weaning, most crossbred genotypes exhibited positive heterosis, with the highest value observed in WFxMU (9.64 %) followed by NDxWF (8.23 %).

At the yearling stage, positive heterosis was observed in half of the genotypes, with the highest value in BOxWF (11.24) followed by GUxWF (8.35). During the grower stage, most genotypes showed negative heterosis, indicating a decrease in performance compared to purebred parents at this stage of growth. At the adult stage, crossbred genotypes exhibited positive heterosis for HL except NDxMU (- 4.83 %), with the highest value in GUxWF (7.57 %) and BOxWF (7.51 %). The Table also contrasts crossbred genotypes with individual purebred parents, highlighting diverse levels of positive or negative relative heterosis for HL at the different growth phases. For instance BOxND, BOxWF, and WFxMU exhibited positive heterosis relative to ND, WF, and MU, respectively across the growth phases but mostly negative heterosis relative to BO. GUxWF exhibited positive heterosis relative to WF across the growth stages except at grower stage but negative heterosis relative to GU except at adult phase. For NDxMU, positive relative heterosis were observed for MU except at weaning while negative heterosis were observed for ND across the growth phases. Generally, for the different hybrid genotypes, heterosis relative to the inferior parents were mostly positive but mostly negative relative to the superior parent.

3.3 Effect of cattle genotype and generation on body length

Table 4 presents data on body length (BL) at

Table 3: Heterosis (%) for head length (cm) at various growth phases for crossbred cattle

Genetic group	Weaning	Yearling	Grower	Adult
Crossbred cattle (G_1)				
BOxND	1.05	-4.98	-0.09	4.13
BOxWF	2.16	11.24	-0.47	7.51
GUxWF	4.86	8.35	-5.12	7.57
NDxMU	-10.69	-1.50	1.70	3.32
NDxWF	8.23	-1.90	-2.65	-4.83
WFxMU	9.64	4.77	2.74	3.93
Overall	2.54	2.66	-0.67	3.58
Differences: crossbred genotype versus (vs) purebred parents				
BOxND vs BO	-4.10	-14.97	-3.80	-4.02
vs ND	7.75	8.43	4.27	13.75
BOxWF vs BO	-0.68	-0.58	-0.96	2.36
vs WF	6.22	26.65	0.43	13.57
GUxWF vs GU	-0.58	-3.16	-6.14	0.91
vs WF	12.04	23.76	-3.59	15.49
NDxMU vs ND	-15.66	-3.45	-4.34	-3.06
vs MU	-4.34	1.54	8.97	12.19
NDxWF vs ND	11.72	-1.18	1.10	-1.26
vs WF	5.93	-1.68	-5.64	-7.66
WFxMU vs WF	1.00	2.30	-6.84	-5.57
vs MU	21.00	7.89	14.75	16.81

various growth phases (weaning, yearling, grower, and adult) for different cattle genotypes for purebred (G_0), and crossbred (G_1) generations.

For the purebred (G_0) generation, BO had the longest BL at all pauses of growth ($P < 0.000$), followed by GU, WF, ND, and MU in decreasing order of values. In the crossbred (G_1) generation, GUxWF hybrids exhibited the longest BL at weaning (119.3 ± 1.47 cm) ($P < 0.000$) followed by BOxWF and BOxND which did not differ significantly but exceeded the remaining genotypes. At yearling stage, GUxWF and BOxWF had statistically similar and highest BL ($P < 0.000$) followed by BOxND, NDxWF, and WFxMU and these did not differ significantly. The highest grower and adult BL were recorded in BOxWF hybrid followed by GUxWF which surpassed other genotypes in this trait. NDxMU recorded the least BL across the growth stages ($P < 0.000$). G_1 hybrid generation recorded significantly higher BL compared to G_0 generation at weaning but statistically similar yearling, grower, and adult BL values.

3.4 Heterosis of body length in crossbred cattle

Table 5 shows that all the G_1 hybrids exhibited positive heterosis for BL across the growth stages except at adult stage when NDxWF and WFxMU expressed negative BL heterosis. GUxWF recorded the highest BL heterosis (11.09 %) at weaning followed by NDxWF with 7.14 % while the least value

Table 4: Body length (cm) at various growth phases for purebred and crossbred cattle

Genetic group	Weaning	Yearling	Grower	Adult
Purebred cattle (G_0)				
BO	117.1 ± 1.57^a	134.5 ± 1.16^a	177.0 ± 1.09^a	180.2 ± 1.37^a
GU	110.4 ± 1.60^b	130.8 ± 1.14^b	169.0 ± 1.07^b	172.8 ± 1.34^b
MU	65.5 ± 1.57^e	102.5 ± 1.16^e	121.2 ± 1.05^d	133.8 ± 1.34^e
ND	87.8 ± 1.69^d	111.0 ± 1.01^d	121.9 ± 1.00^d	140.3 ± 1.18^d
WF	102.4 ± 1.54^c	118.3 ± 1.14^c	135.4 ± 1.05^c	159.8 ± 1.20^c
P-value	0.000	0.000	0.000	0.000
Mean G_0	96.8 ± 1.72^B	119.0 ± 1.05	143.6 ± 1.93	156.4 ± 1.62
Crossbred cattle (G_1)				
BOxND	108.5 ± 1.44^b	124.2 ± 1.08^b	151.6 ± 0.92^c	163.6 ± 1.13^c
BOxWF	111.0 ± 1.44^b	132.7 ± 1.08^a	172.4 ± 0.96^a	175.3 ± 1.11^a
GUxWF	119.3 ± 1.47^a	131.0 ± 1.08^a	161.1 ± 1.01^b	168.2 ± 1.13^b
NDxMU	80.7 ± 1.41^e	92.9 ± 1.11^c	120.6 ± 0.94^f	138.0 ± 1.13^e
NDxWF	101.2 ± 1.30^c	121.3 ± 1.00^b	133.5 ± 0.92^e	147.9 ± 1.09^d
WFxMU	88.4 ± 1.58^d	121.5 ± 1.02^b	137.3 ± 0.97^d	146.2 ± 1.09^d
P-value	0.000	0.000	0.000	0.000
Mean G_1	101.6 ± 1.25^A	120.8 ± 1.11	145.7 ± 1.38	156.4 ± 1.16

a,b,c,d,e: means on the same column with different lower case superscripts are significantly different within generations (P = 0.05); A, B: means on the same column with different uppercase letters are significantly different between generations (independent samples t-test).

was observed in BOxWF (0.38 %). At yearling, highest BL heterosis was observed in NDxMU (25.21 %) followed by WFxMU while BOxND recorded the least value.

Grower, and adult NDxMU had the highest BL heterosis followed by BOxWF counterparts while BOxND, and WFxMU recorded the least values for BL heterosis at grower and adult stage, respectively. Mean BL heterosis was positive across the growth stages but significant only at weaning. Highest mean BL heterosis was however, recorded at yearling (9.08) followed by grower stage (8.06). The Table further provides comparisons of crossbred with specific purebred genotypes, revealing varying levels of positive and negative heterosis depending on the cross and growth phase. Relative BL heterosis was positive across growth phases for BOxND relative to ND, BOxWF and GUxWF relative to WF, NDxMU and WFxMU relative to MU, and for NDxWF relative to ND. Generally, for each crossbred genotype, heterosis was positive relative to the inferior parent genotype in the cross but mostly negative relative to the superior purebred genotype in the cross. For instance negative relative BL heterosis was observed for BOxND, and BOxWF relative to BO across the growth stages, and for GUxWF relative to GU across the growth stages except at weaning (8.12 %). Similarly, negative relative heterosis was recorded for NDxMU relative to ND at weaning, for NDxWF relative to WF at weaning, grower, and adult stages, and for WFxMU relative to WF at weaning and adult stages.

Table 5: Heterosis (%) for body length at various growth periods for crossbred cattle

Genetic group	Weaning	Yearling	Grower	Adult
Crossbred cattle (G_1)				
BOxND	5.82	1.03	1.22	2.14
BOxWF	0.38	4.85	10.51	2.75
GUxWF	11.09	4.96	5.72	1.35
NDxMU	5.74	25.21	19.59	18.52
NDxWF	7.14	5.93	3.96	-1.33
WFxMU	3.80	10.25	6.99	-0.61
Overall	5.70*	9.08	8.06	3.61
Differences: crossbred genotype versus (vs) purebred parents				
BOxND vs BO	-7.27	-7.70	-14.40	-9.15
vs ND	24.34	11.94	24.68	16.94
BOxWF vs BO	-4.85	-1.42	-2.41	-2.95
vs WF	6.90	12.16	27.62	10.01
GUxWF vs GU	8.12	-0.09	-4.62	-2.39
vs WF	15.11	10.69	18.84	5.56
NDxMU vs ND	-7.00	8.82	2.68	10.14
vs MU	23.46	13.65	15.29	19.34
NDxWF vs ND	17.22	9.66	9.79	5.60
vs WF	-0.26	2.71	-1.13	-7.31
WFxMU vs WF	-15.21	2.81	1.53	-8.35
vs MU	34.64	19.18	13.31	9.10

*: significant (P = 0.05) when crossbred performance was compared with the purebred (G_0) generation.

3.5 Effect of cattle genotype and generation on chest girth

Table 6 presents records on chest girth (CG) of the experimental animals at different growth stages. As expected, significant differences in CG were observed among purebred cattle breeds at all ages. The GU had significantly (P < 0.00) higher CG compared to other genotypes at weaning, grower, and adult stages while the trait was statistically similar (P > 0.05) for GU and BO at the yearling stage. The GU was followed by BO with significantly (P < 0.00) higher CG than WF, ND, and MU across the stages of growth.

Statistically similar CG were recorded for ND and WF at weaning, and at yearling in addition to MU, and for MU and ND at grower stage. Statistically lowest CG values were observed in MU cattle at weaning and adult stages (P < 0.000). Among the crossbred genotypes, BOxWF and GUxWF recorded the highest CG (P < 0.000). This was followed by BOxND and NDxWF at weaning stage, by BOxND at yearling and adult stages, and by BOxND, NDxWF, and WFxMU at grower stage. BOxND and NDxWF had statistically similar CG at weaning, and these significantly (P < 0.000) surpassed the value for WFxMU which was also higher compared to the weaning CG for NDxMU. At yearling stage, CG of BOxND was significantly (P < 0.000) higher compared to that of NDxWF which in turn was higher than that of NDxMU. WFxMU recorded the least CG at this stage. BOxND, NDxWF, and WFxMU had statistically similar (P > 0.000) CG at grower stage.

Table 6: Chest girth (cm) at different growth phases for purebred and crossbred cattle

Genetic group	Weaning	Yearling	Grower	Adult
Purebred cattle (G_0)				
BO	103.2 ± 1.52^{b}	120.9 ± 1.84^{a}	140.9 ± 1.13^{b}	156.1 ± 1.20^{b}
GU	115.5 ± 1.50^{a}	123.7 ± 1.78^{a}	147.5 ± 1.13^{a}	164.4 ± 1.20^{a}
MU	73.4 ± 1.50^{d}	101.2 ± 1.80^{b}	120.1 ± 1.13^{d}	125.8 ± 1.20^{e}
ND	93.8 ± 1.47^{c}	104.3 ± 1.75^{b}	119.3 ± 1.13^{d}	135.7 ± 1.20^{d}
WF	91.4 ± 1.47^{c}	105.2 ± 1.80^{b}	127.0 ± 1.13^{c}	148.0 ± 1.20^{c}
P-value	0.000	0.000	0.000	0.000
Mean G_0	95.4 ± 1.34	111.0 ± 1.10^{B}	131.0 ± 1.01^{A}	146.0 ± 1.23
Crossbred cattle (G_1)				
BOxND	96.3 ± 1.39^{b}	116.2 ± 1.10^{b}	125.1 ± 0.86^{b}	149.9 ± 1.28^{b}
BOxWF	104.2 ± 1.39$_{a}$	121.3 ± 1.08$_{a}$	137.8 ± 0.86$_{a}$	157.4 ± 1.28$_{a}$
GUxWF	103.7 ± 1.36^{a}	121.4 ± 1.08^{a}	136.7 ± 0.86^{a}	155.5 ± 1.28^{a}
NDxMU	78.2 ± 1.39^{d}	108.0 ± 1.08^{d}	120.9 ± 0.86^{c}	128.6 ± 1.28^{e}
NDxWF	95.1 ± 1.34^{b}	111.9 ± 1.10^{c}	125.0 ± 0.86^{b}	139.1 ± 1.28^{d}
WFxMU	86.7 ± 1.34^{c}	104.7 ± 1.12^{e}	122.9 ± 0.86^{bc}	145.0 ± 1.28^{c}
P-value	0.000	0.000	0.000	0.000
Mean G_1	94.0 ± 0.91	114.0 ± 0.64^{A}	128.1 ± 0.58^{B}	145.9 ± 0.89

a,b,c,d,e: w ithin generations, means on the same column with different lower case superscripts are significantly different (P = 0.05).

NDxMU had the least value for CG at this stage and this was similar to the value for WFxMU. For adult cattle, BOxND surpassed WFxMU which in turn surpassed NDxWF while the least value (P < 0.000) for adult cattle CG was recorded in NDxMU. Except for yearling CG, NDxMU recorded the narrowest CG across the other growth stages (P < 0.000). Table 6 also compared the generation mean CG for purebred and crossbred cattle. At weaning and adult stages, statistically similar (P > 0.05) mean CG were observed for purebred and G_1 hybrid genotypes. Mean yearling CG was higher (P < 0.017) in G_1 compared to G_0 while mean grower CG was higher (P < 0.013) in G_0 compared to G_1.

3.6 Heterosis of chest girth in crossbred cattle

Table 7 details the heterosis for CG across the growth stages for the various crossbred genotypes relative to purebred generation, and individual purebred parents. The results show that the G_1 crossbred cattle exhibited significant positive heterosis for CG at yearling (5.40 %) and grower stages (0.18 %) while at weaning and adult stages heterosis for CG were positive but non-significant. For specific hybrid genotypes, BOxWF, WFxMU, NDxWF, and GUxWF showed positive heterosis at weaning while BOxND and NDxMU exhibited negative heterosis for CG at this stage. BOxWF had the highest weaning CG heterosis (6.74 %) followed by WFxMU (5.75 %) while the least positive heterosis was recorded in GUxWF hybrids (0.73 %). At yearling stage, CG heterosis was positive for all hybrid genotypes with NDxWF having the highest value (7.24 %) followed by GUxWF (6.89 %) and BOxWF (6.63 %) while WFxMU exhibited the least CG heterosis (1.89 %) at this stage. Heterosis of CG at grower stage was positive for BOxWF (2.56 %), NDxMU (1.15 %) and NDxWF (1.74 %) but negative for BOxND, and GUxWF.

Table 7: Heterosis (%) for chest girth at different growth phases for crossbred cattle

Genetic group	Weaning	Yearling	Grower	Adult
Crossbred cattle (G_1)				
BOxND	-1.06	3.95	-3.71	2.79
BOxWF	6.74	6.63	2.56	3.27
GUxWF	0.73	6.89	-0.30	-0.42
NDxMU	-4.80	5.71	1.15	-1.59
NDxWF	3.40	7.32	1.74	-1.89
WFxMU	5.75	1.89	-0.37	5.98
Overall	1.86	5.40*	0.18*	1.36
Differences: crossbred genotype versus (vs) purebred parents				
BOxND vs BO	-5.97	-3.41	-11.11	-3.73
vs ND	5.48	12.34	5.38	10.54
BOxWF vs BO	1.78	0.46	-2.03	1.20
vs WF	15.22	16.06	8.87	6.40
GUxWF vs GU	-9.80	0.08	-7.24	-5.28
vs WF	14.38	16.15	8.04	5.13
NDxMU vs ND	-14.32	4.43	1.78	-5.12
vs MU	8.43	7.31	0.86	2.41
NDxWF vs ND	3.32	8.03	5.28	2.61
vs WF	4.65	7.07	-1.23	-5.94
WFxMU vs WF	-4.38	0.36	-2.81	-1.98
vs MU	15.60	4.04	2.53	15.57

*: significant (P = 0.05) when crossbred generation was compared with the purebred (G_0) generation (independent samples t-test).

At adult stage, heterosis for CG was positive and highest in WFxMU hybrids (5.98 %) followed by BOxWF and BOxND (3.27 and 2.79 %, respectively) while GUxWF, NDxMU, and NDxWF exhibited negative heterosis at this stage. Across growth phases, mean CG heterosis was positive but significant only for yearling (5.40 %) and grower (0.18 %) values. In comparison to specific purebred parents, heterosis was positive for BOxND relative to ND but negative relative to BO across the growth stages. BOxWF exhibited positive CG heterosis relative to WF across the growth phases, and relative to BO at all growth phases except at grower phase. GUxWF, NDxMU, NDxWF and WFxMU had positive heterosis relative to WF, MU, ND, and MU, respectively across the growth stages. Heterosis relative to GU by GUxWF and relative to WF by WFxMU were positive only for yearling CG. For NDxMU, heterosis relative to ND was positive for yearling and grower CG while for NDxWF relative to WF, positive heterosis were observed for weaning and yearling CG.

3.7 Effect of cattle genotype and generation on height at withers

Table 8 displays the height at withers (HW) across the different age periods for the various cattle genotypes within purebred, and crossbred generations. Within the purebred generation (G_0), significant differences in HW were observed among the purebred cattle breeds at all ages. GU had the highest HW ($P < 0.000$) across the growth stages followed by BO and WF at weaning and yearling stage, and BO at grower and adult stage. The least values for HW were observed in MU cattle across the age periods.

Table 8: Height at withers (HW, cm) at various growth phases for purebred and crossbred cattle

Genetic group	Weaning	Yearling	Grower	Adult
Purebred cattle (G_0)				
BO	91.5 ± 1.68^{b}	99.9 ± 1.08^{ab}	117.9 ± 1.27^{b}	137.2 ± 1.18^{b}
GU	98.2 ± 1.58^{a}	101.9 ± 1.12^{a}	123.9 ± 1.27^{a}	143.2 ± 1.18^{a}
MU	66.9 ± 1.58^{d}	71.4 ± 1.12^{d}	94.2 ± 1.27^{e}	108.5 ± 1.18^{e}
ND	78.4 ± 1.42^{c}	92.6 ± 1.00^{c}	102.2 ± 1.19^{d}	119.5 ± 1.18^{d}
WF	87.3 ± 1.44^{b}	98.5 ± 1.03^{b}	111.2 ± 1.27^{c}	131.3 ± 1.18^{c}
P-value	0.000	0.000	0.000	0.000
Mean G_0	$84.2 \pm 1.13_{B}$	$93.1 \pm 1.01_{B}$	$109.7 \pm 1.02_{B}$	$127.9 \pm 1.13_{B}$
Crossbred cattle (G_1)				
BOxND	90.8 ± 1.58^{c}	99.6 ± 1.43^{c}	118.2 ± 0.92^{b}	135.9 ± 0.83^{b}
BOxWF	101.9 ± 1.48^{a}	105.5 ± 1.40^{b}	117.8 ± 0.88^{b}	137.3 ± 0.83^{ab}
GUxWF	96.1 ± 1.51^{b}	111.5 ± 1.38^{a}	116.3 ± 0.89^{b}	138.8 ± 0.83^{a}
NDxMU	75.4 ± 1.54^{e}	87.1 ± 1.43^{e}	104.6 ± 0.92^{c}	117.9 ± 0.83^{e}
NDxWF	91.9 ± 1.48^{bc}	95.0 ± 1.33^{d}	124.5 ± 0.89^{a}	130.8 ± 0.83^{c}
WFxMU	84.8 ± 1.45^{d}	89.1 ± 1.38^{e}	103.0 ± 0.92^{c}	126.1 ± 0.83^{d}
P-value	0.000	0.000	0.000	0.000
Mean G_1	90.3 ± 0.92^{A}	98.0 ± 0.88^{A}	114.3 ± 0.67^{A}	131.1 ± 0.63^{A}

a,b,c,d,e: within generations, means on the same column with differ ent lower case superscript s are significantly different (P = 0.05); A, B,C: between generations, means on the same column with different uppercase superscripts are significantly different (P = 0.05).

Although there were no significant differences at weaning and yearling stage between BO and WF, HW was significantly different between the two breeds at the grower and adult stages (P < 0.000). For crossbred genotypes, BOxWF and GUxWF had consistently higher HW compared to other genotypes except at grower stage when NDxWF animals surpassed other genotypes (P < 0.000). BOxND closely followed BOxWF and GUxWF with the third highest HW across most of the growth stages. Except at the grower stage, HW was significantly lowest in NDxMU compared to other genotypes. Table 8 also compared generational mean HW values for purebred (G_0), and crossbred (G_1) generations. Across the growth stages, mean HW was significantly higher for G_1 compared to G_0 (P < 0.000).

3.8 Heterosis of height at withers in crossbred cattle

Table 9 presents the hybrid (G_1) heterosis for HW relative to G_0 generation, and individual purebred parents. Hybrid (G_1) mean heterosis for HW were positive across the growth stages however, significant values were recorded at weaning, yearling, and grower stages. Highest overall G_1 heterosis (7.57 %) was observed for weaning HW while the least (3.88 %) was observed for adult HW. Comparison of crossbred genotypes with individual purebred parent genotypes revealed varying levels of positive and negative heterosis depending on the genotype and growth stage. Heterosis of HW for BOxND relative to ND were positive across the growth stages but positive only for grower HW relative to the BO parent. For BOxWF hybrids, heterosis relative to BO was positive at weaning, yearling, and adult stages but negative at grower stage. In contrast, heterosis of HW was positive across the growth stages with reference to the WF parent.

Table 9: Heterosis (%) of height at withers (HW) at various growth phases for crossbred cattle

Genetic group	Weaning	Yearling	Grower	Adult
Crossbred cattle (G_1)				
BOxND	6.07	3.86	7.41	5.94
BOxWF	13.44	6.39	2.88	2.42
GUxWF	3.58	11.49	- 0.60	1.28
NDxMU	3.10	6.59	6.85	3.67
NDxWF	9.25	- 0.35	17.18	4.49
WFxMU	9.69	5.44	0.81	5.46
Overall	7.57*	5.46*	5.76*	3.88
Difference: crossbred genotype versus (vs) purebred parents				
BOxND vs BO	- 0.40	- 0.05	0.31	- 0.74
vs ND	14.32	8.46	15.79	13.88
BOxWF vs BO	11.80	6.11	- 0.24	0.27
vs WF	16.16	7.21	6.66	4.94
GUxWF vs GU	- 1.53	9.95	-5.80	- 2.97
vs WF	9.73	13.17	5.68	6.07
NDxMU vs ND	- 5.15	- 5.21	2.62	- 1.14
vs MU	13.90	22.32	12.07	9.47
NDxWF vs ND	15.06	3.46	21.80	9.65
vs WF	4.86	- 3.56	13.00	-0.02
WFxMU vs WF	- 3.38	- 9.52	- 6.51	- 3.66
vs MU	27.29	25.79	10.16	16.91

* Significant (P = 0.05) when crossbred (G_1) generation was compared with purebred (G_0) generation (independent samples t-test).

Similarly, heterosis of HW for GUxWF relative to WF, NDxMU relative to MU, NDxWF relative to ND, and WFxMU relative to MU were positive across the growth stages. Heterosis of HW for GUxWF relative to GU was negative at weaning, grower, and adult stages but positive at yearling stage. For NDxMU relative to ND, positive heterosis was observed at the grower stage while for NDxWF relative to WF, positive heterosis were observed for weaning and grower HW. Heterosis of HW for WFxMU relative to WF was negative across the age periods.

1. Discussion

The present study was designed to evaluate and compare the linear body traits of purebred and F1 hybrid cattle genotypes, and determine the heterosis of the linear body traits in a humid rainforest zone. The higher HL observed in GU and BO compared to MU, ND, and WF especially at weaning, yearling, and adult stages of growth reflect the superior growth potentials usually attributed to GU and BO (7, 45, 46). As expected, MU cattle had the least HL across the growth stages which corresponds to the small stature of this breed. Meanwhile, MU is known for its hardiness, disease resistance, and small body size which could be adaptations for survival in the harsh tropical environment (24). Significant breed differences in HL were reported by (7) with GU having longest HL (57.7 cm) followed by WF (46.6 cm) and then ND (35.4 cm). Another study (47) had reported significantly longer HL in WF cattle during rainy season compared to values for ND and MU which in turn did not differ significantly in this trait. The authors however, reported non-significant differences between the cattle breeds in this trait during dry season, and for pooled values across seasons. In a study of linear body traits of four cattle breeds, (48) reported statistically similar face length in Adamawa Gudali, Sokoto Gudali, White Fulani, and Red Bororo in cattle of 8 months to one year of age, while in those of one to three years of age, longest face length was observed in Sokoto Gudali (44.34 ± 0.36 cm) followed by Red Bororo (43.65 ± 0.36 cm), WF (40.87 ± 0.42 cm), and Adamawa Gudali (38.94 ± 0.50 cm). Face length is directly related to head length. Elsewhere, (49) studied linear body traits of nine beef cattle breeds, and observed longest HL in Lincoln Red (52.8 cm) followed by Shaver and Blonde d'Aquitaine (52.1 and 52.0 cm, respectively) while Hereford had the shortest length of head (47.9 cm). The observed longer HL in GUxWF and BOxWF genotypes compared to other G_1 hybrids at yearling and adult stages reflect the effect of favourable breed combination on the trait. The significantly higher HL in BOxND and NDxWF cattle compared to NDxMU is expected given the superior growth attributes of the zebu breeds and the favourable effect of breed complementarity on HL. ND and MU are known for their trypanotolerance but, are inferior to the Zebu breeds (GU, BO, and WF) in growth attributes (47). Consequently, crosses involving the zebu breeds had longer HL compared to hybrids of ND and MU.

Even though mean HL heterosis were not statistically significant, they were positive across the growth stages except at grower stage. This indicates gain in HL following crossbreeding. The mostly positive heterosis by specific crossbred genotypes at weaning, yearling, and adult stages indicate superior growth attributes of the hybrids compared to the mean of their purebred parents. This is likely because the F_1 crossbred generation benefits from maximum heterosis resulting in increased vigor, better adaptation, and improved performance compared to their purebred parents (50, 51). The negative HL heterosis observed for most hybrids at the grower stage could be as a result of variation in age and sex distribution of animals measured in purebred and crossbred genotypes and/or trade-offs between growth and other traits as hybrids may allocate resources differently at this stage.

The positive HL heterosis recorded by most hybrids relative to the inferior parent in each cross and the negative heterosis by the hybrids relative to the superior parents, suggest that hybrid vigor effect is influenced by the specific purebred parents involved in a cross. The positive inferior parent heterosis for HL indicate genetic improvement (upgrading) of the inferior parents in HL following crossbreeding. Positive and negative heterosis, and relative heterosis were reported in linear body traits of cattle by previous studies (44, 52, 53).

The highest BL observed in BO followed by GU across the stages of growth imply that these breeds are the longest among the breeds evaluated in the present study. Similarly, the shortest BL observed in MU cattle across the growth stages support the dwarf stature of this genotype. The results agreed with (48) who reported higher BL in Sokoto Gudali and Red Bororo of 8 months to 1 year of age compared to WF. Higher BL was reported in WF compared to MU (54, 55) as was reported in the present study. The results also agree with (46) who reported significantly higher BL in Sokoto Gudali compared to White Fulani (Bunaji) (95.32 versus 92.88 cm). In contrast to the results presented, (47, 56) observed statistically similar BL in adult WF, ND, and MU. The study by (57) also reported statistically similar BL in adult WF and BO which contradicts the results of the present study. The observed longer BL in GUxWF and BOxWF hybrids (crosses between zebu breeds) compared to other genotypes across the growth stages reflect the favourable effect of breed complementarity. Similarly, the superior BL of BOxND and WFxMU animals compared to NDxWF and NDxMU counterparts across the growth stages reflect the positive effect on BL of using the zebu breeds (BO and WF) as sires. The higher mean BL observed for G_1 crossbred generation at weaning compared to purebred (G_0) generation indicate improved BL in the crossbred animals. The similar BL between purebred and hybrid generation for yearling, grower, and adult phases could be due to genetic interaction effects whereby, the expression of some growth genes favour growth at some stages of growth more than others. The results are in agreement with (44) who reported inconsistent trend in gain in linear body traits at various ages between purebred (G_0) and hybrids of crosses between Nellore and Charolais cattle genotypes.

The predominant positive BL heterosis observed in crossbred (G_1) generation indicates that the cattle breeds when optimally combined in a crossbreeding programme could enhance BL and therefore the growth performance of the crossbred genotypes. The observed variation in heterosis relative to individual purebred parent genotypes align with (39), highlighting breed-specific heterosis differences. Their work underscores the strategic utilization of these differences in mating plans to achieve varying levels of hybrid vigor. Overall, the comparisons with purebred genotypes underscore the complexity of heterosis effects and the need for careful consideration of parental breed combination, trait, and age-dependent effects to optimize hybrid vigor in livestock breeding programmes (58).

The observed significant variation in CG within purebred and hybrid genotypes reflects their inherent genetic differences in growth and body conformation. The results indicate significant genetic effect of breed and breed combination on this trait. The broadest chest observed in GU followed by BO and then WF and ND agrees with (45) who reported highest CG in Sokoto Gudali and Red Bororo (159.4 ± 2.9 and 152.8 ± 2.0 cm, respectively) followed by Adamawa Gudali (145.4 ± 1.3 cm), WF (145.3 ± 3.4 cm), MU (127.0 ± 4.4 cm), and ND (121.6 ± 2.7 cm). The least value for CG observed in MU was expected given their dwarf phenotype (59). The study by (46) reported higher CG in Sokoto Gudali compared to WF in agreement with the present study. In contrast to the findings reported here, (60) reported higher CG in WF compared to GU while (48) observed non-significant differences in CG of Adamawa Gudali, Sokoto Gudali, White Fulani, and Rahaji (Red Bororo) at 8 months to one year of age. The non-significant differences in CG between WF and ND at weaning, and between WF, ND, and MU at yearling stage could be attributed to differences in the age distribution of animals included in these growth phases. The results however, agreed with (47) who reported statistically similar CG between adult ND, MU, and WF cattle. Elsewhere, (52) reported higher values for thoracic perimeter (chest girth) in Charolais (C) compared to Nellore (N) at 8, 12, and 18 moa while both breeds had statistically similar values for the trait at 24 moa. In their own study, (44) observed higher gain in thoracic girth in N breed compared to C at 1-63 days of age. Both breeds did not differ statistically at 63-210 days of age, while C gained higher in thoracic girth at 210-365 and 1-365 days of age. The inconsistent trend in superiority of one breed over the other in growth performance indicate the effect of genetic interactions (dominance and/or epistasis) as well as the effect of genetic x environment interaction (61). The reported higher CG in crosses of the zebu breeds (BOxWF and GUxWF), and the hybrid BOxND is attributable to favourable breed combination (breed complementarity), and sire effects. The results suggest that the selection of GU and BO as sires could enhance linear body traits such as CG through breed complementarity, and sire effect (53). Good thoracic development was reported to be important for efficient respiration, fitness, and meat yield in beef cattle (7). The non-significant variation in mean CG values between G_0 and G_1 generations agreed with (52) who reported generation mean values for thoracic perimeter that did not differ significantly between G_0 and G_1 generations at 8 months of age.

The positive heterosis for CG observed in G_1 (significant at yearling and grower stages) suggests favourable effect of crossbreeding on thoracic development. The results implies that most of the crossbred animals had better fitness and were more efficient beef animals compared to the purebred parents. The observed negative heterosis especially for adult cattle could result from variations in age and sex distribution of animals within purebred and crossbred groups at this growth stage. Furthermore, genes for growth may be expressed differently in purebred and crossbred animals at the adult stage. It has been shown that heterosis is not uniformly beneficial or advantageous (62). Consequently, the mean of hybrid performance could be higher, lower or similar to the average for the purebred parents over the course of growth. In the study by (44), G_2 heterosis for gain in thoracic girth was positive but not significant at 1-63 and 1-365 day of age and negative at 63-210 and 210-365 day of age. The implication of the mostly positive relative heterosis (heterosis relative to individual purebred parents) observed across the growth stages is that the performance of the crossbred genotypes were mostly superior to those of the purebred parents involved in the crosses especially with regards to the inferior parent of each cross. Positive and negative values for relative heterosis of morphometric traits were reported previously (44, 52). Negative G_1 heterosis relative to Charolais was reported at 8 moa for thoracic perimeter, positive values were reported at 12, 18, and 24 months of age while relative to Nerolle, heterosis were positive across the ages of growth (52). For gain in thoracic girth, heterosis relative to Charolais was positive at 1-63, and 63-210 day but negative at 210-365, and 1-365 day. Relative to Nerolle, negative heterosis was reported at 1-63 day while positive values were reported at 63-210, 210-365, and 1-365 day (44).

The significantly higher HW observed in GU across the growth stages compared to other purebred genotypes sets this breed apart as the tallest amongst the breeds evaluated in this study. GU was closely followed by BO and WF thus confirming the superiority of these breeds over ND and MU. The significantly lowest HW observed in MU across the growth stages confirms the dwarf stature of this breed. The results disagree with (60) who observed higher HW in WF (129.6 ± 0.31 cm) compared to Sokoto Gudali (127.65 ± 0.40), (56) who reported higher HW in ND compared to WF, and (57) who observed statistically similar HW between WF, Adamawa Gudali, and Red Bororo. The results however, agreed with some other previous studies (45, 48, 54, 55). Higher HW was reported by (54, 55) in WF compared to MU. The effects of age and breed on linear body measures of Adamawa Gudali, Sokoto Gudali, White Fulani, and Rahaji (Red Bororo) was studied by (48) who reported highest HW in Sokoto Gudali and Rahaji compared to other breeds. In their own study, (56) observed higher HW in ND compared to MU. Highest HW was reported in Red Bororo (133.8 ± 1.4 cm) followed by Sokoto Gudali (130.9 ± 2.0 cm) compared to 121.8 ± 2.2, 121.4 ± 1.0, 105.3 ± 2.0, and 95.4 ± 3.1 cm for Adamawa Gudali, WF, ND, and MU, respectively by (45). As with other linear body traits, the superior HW of hybrids of zebu breeds (GUxWF, and BOxWF), and hybrids of zebu sires (BOxND) compared to hybrids of taurine crosses (NDxMU) or of taurine sires (NDxWF) indicate breed complementarity, and favourable sire effects. The significantly higher HW in hybrid (G_1) generation compared to purebred (G_0) generation across growth stages indicate favourable effect of crossbreeding on growth of the animals, and this is in agreement with previous studies (44, 52). Higher gain in rump height in hybrids of Charolais and Nellore cattle compared to the mean of purebred parents at 18 and 24 months of age was reported by (52).

The positive and significant heterosis observed between purebred and crossbred generations confirm the effectiveness of crossbreeding in improving HW in the crossbred population. Significant G_1 heterosis for rump height were reported by (52) at 18 and 24 moa. In the study by (44), heterosis for gain in croup height was positive at 1-63, 63-210, and 1-365 day but only the value for 1-365 day was significant. The positive relative heterosis (heterosis relative to individual purebred parents) indicate enhanced performance of the crossbred animals compared to their individual purebred parents especially relative to the inferior parent in each cross. In the report of (44), heterosis relative to performance of Charolais was positive across the ages, while that relative to Nerolle was negative except at 365 day.

2. Conclusions and Applications

1. Linear body measurements complement body weight in the objective assessment of animal performance, and market value by farmers, cattle dealers, breeders, and veterinarians.
2. Significant genotypic effects were observed on linear body traits, and in heterosis relative to mean of parental values, and individual parents. This information will aid selection and further genetic improvement of indigenous cattle genotypes.
3. The observed positive heterosis in linear body traits could be exploited in composite breeding to produce cattle genotypes suited to the humid rainforest agro-ecology of Nigeria.

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Ethical Approval

The research protocols and methodology for this study was approved by the Ethics Committee on Welfare and Use of Animals in Research, Michael Okpara University of Agriculture Umudike dated September 3, 2021.

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