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Effects of Body Indices and Shoeing on Hoof Morphometry among Sudanese Country-Bred Polo Horses in Nigeria

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ABSTRACT

Several factors influence hoof size which largely determine the normal function of the equine limbs. The effects of shoeing and body indices on hoof morphometry among Sudanese country-bred polo horses in Nigeria were evaluated in the present study. Apparently healthy, shod/barefooted Sudanese country-bred mares without hoof abnormalities were randomly selected and included in the present study. As body indices, we measured the height at withers, heart-girth, body length, and body weight; as hoof parameters, we measured the toe length, solar length, hoof width, and dorsal and ventral hoof wall width on all limbs. Pearson correlation analysis and the independent sample T test were applied for data analysis. The mean height, body weight, heart girth and body length of the Sudanese country-bred horses were 1589.5 ± 56.0 mm, 430.8 ± 42.9 kg, 1758.8±65.31mm and 1649.4±50.03mm respectively which were not significantly different between the shod and barefooted. The dorsal hoof wall width and the hoof solar length and width between the shod and barefooted groups differed statistically significantly ($p<0.05$). In Sudanese country-bred mares, there was a strong positive correlation that was different significantly between the heart-girth, body length, and body weight. Hoof morphometry and body indices showed a strong positive correlation. The most important ratios relating to hoof size differences between horses with shoes and those without were the hoof index, length, and width to body measurement ratios. According to this study, Sudanese Country-bred horses' hoof morphometry is significantly impacted by shoeing and body indices.

Keywords: Horse; Shoeing; Morphometry; Body traits; Hoof traits

INTRODUCTION

Equine hooves are made of horny tissue that covers the distal end of the digit (Getty, 2012). Its shape determines how the foot moves in relation to the earth and directly affects the magnitude and direction of forces that enter the limb (Eliashar *et al.,* 2004). The equine hoof's high body mass to weight-bearing surface ratio causes considerable, recurring impact loads during movement (Warner *et al.,* 2013). Consequently, poor foot pathologies have been linked to up to 70–80% of cases of lameness, and foot problems are common (Holzhauer *et al.,* 2017).

Equine hoof's evolutionary structure facilitates mobility by offering leverage, support, and shock absorption (Leśniak *et al.,* 2019). According to Stachurska *et al.* (2011), a hoof's ability to support the horse's body mass adequately is largely dependent on its size. A hoof that is too small will not be able to function properly and will eventually result in foot lameness (Redden, 1997). In addition to different breed of horses, the age of the animals should be considered when analyzing the hoof size in relation to body size (Stachurska *et al.,* 2011). Up until the age of six years, the size of the hoof increases, and older horses' larger hooves grow more slowly (Stachurska *et al.,* 2011). According to Stachurska *et al.* (2011), the width is the most distinctive hoof dimension for the breed. The height of the horses at withers and the hoof parameters showed some weakly positive correlations, according to Kummer *et al.* (2006). The best way to gauge hoof size in relation to body size is also to look at the ratio of hoof width to chest circumference (Stachurska *et al.,* 2011).

Numerous research have focused on the equine hoof balance, and morphometry has been used to gather pertinent data on the traits of various breeds and the conditions in which horses are handled (Nicoletti *et al.,* 2000; Canto *et al.,*2006; Sargentini *et al.,* 2012; Schade *et al.,* 2013; Dau *et al.,*2015; Souza *et al.,* 2016; Tocci *et al.,* 2017; Mostafa *et al.,* 2020; Souza *et al.,* 2021). According to Kawareti *et al.* (2017b), the hoof is a crucial part of the equine movement apparatus, and improper hoof balance can cause lameness and other foot problems. The differentiation of the hoof capsule form and subsequent

effects on hoof symmetry are caused by distinct functions and biomechanics of the fore and hind limb. The significance of foot conformation as a risk factor for musculoskeletal injury has been brought to light by certain clinical studies (Kane *et al.*, 1998).

Since the hoof's purpose is to support an animal's weight and counteract external stresses during locomotion, hoof pathologies and related shape variations have a significant impact on the health of equines, and these have baffled humankind for centuries (Harris, 2012). Overweight has been connected to musculoskeletal disorders (Wearing *et al*., 2006), including osteoarthritis of the knee (Toivanen *et al.,* 2010) and hip (Recnik *et al.,* 2009); foot and distal limb pathologies have also been linked to this, due to increased loading (Wearing *et al.,* 2006; Recnik *et al.,* 2009). There hasn't been much research done on how body mass affects hoof geometry thus far. Hoof issues account for most of the lameness in horses (Baxter, 2020). It is believed that a variety of risk factors, many of which are still poorly understood, influence how hoof abnormalities are distributed.

Provision of guidelines for hoof imbalances is an important role of hoof morphometry. Knowledge of hoof morphometry can be harnessed to ensure precise trimming and shoeing as well as assess the presence of issues such as contracted heels, under run heels, sheared heels and mismatched hoof angles (Shahkhosravi *et al.,* 2022). These parameters provide information about the limb's soundness and help horse owners assess their financial losses from veterinary care, training costs, investments in animal selection, and other expenses. Despite the studies on the hoof morphometry in relations to body size and hoof conformation, the impact of a horse's height and body mass on the morphometry and symmetry of their hooves is poorly understood. Therefore, this study aimed to evaluate the effect of body indices and shoeing on hoof morphometry among Sudanese country-bred polo horses in Nigeria.

MATERIALS AND METHODS

Study design

This study was a purposive cross-sectional study carried out in different polo clubs in Oyo State, Nasarawa State, FCT, Kaduna State and Kano State, Nigeria. The study was approved by College Research Ethical Committee of the College of Veterinary Medicine, Federal University of Agriculture Abeokuta Ogun State Nigeria with approval number FUNAAB/COLVET/CREC/2018/07/02. Also, owner informed consent for their horses to participate in the study was sought and approved.

Animals

The study included 34 healthy, shod or barefoot Sudanese country-bred mares aged 12-15years without hoof abnormalities. Detailed history of each horse was obtained through a structured questionnaire. Each horse was restrained by the handler for hoof and body measurements after obtaining their individual history.

Measurement of horse body indices

The following body traits were measured to determine body indices, (Figure 1).

- height at withers (measured from ground level to highest point at withers around third thoracic vertebrae);
- Heart girth (measured at the third thoracic vertebrae);
- Body length (measured from the point of the shoulder to a line perpendicular to the point of the buttock).

$$\text{Bodyweight (Kg)} = \frac{\text{Bodylength} * \text{Heartgirth}^2}{11{,}880\text{cm}^2}$$

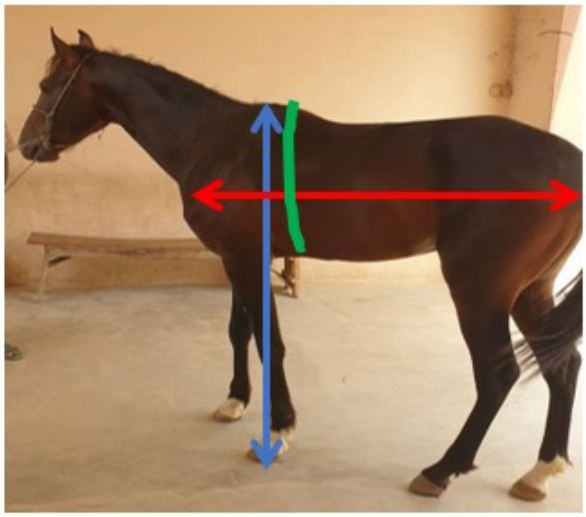

Figure 1: The Height (Blue line), Body length (Red line) and Heart-Girth (Green line) as body indices measured in Sudanese country bred horses.

Hoof Morphometry

Each of the hooves was measured using tape rule and digital vernier caliper. In addition, photographs of each hoof were taken using digital camera. All measurements were recorded in millimeters. The following hoof parameters were measured in each of the horses:

- **Toe length:** measured from the coronary rim of the hoof to the centre of the end of the toe;
- **Hoof solar length**: measured from the centre of the toe to the heel buttress line excluding the heel bulb;
- **Hoof solar width:** measured at the widest part of hoof starting from medial to lateral quarter at the solar side;
- **Dorsal hoof wall width:** measured at the widest part of the dorsal part of the hoof to end at the beginning of hoof buttress;
- **Ventral hoof wall width:** measured between heel buttresses points of the hoof.

The following parameters were also determined from the hoof and body traits measurements gotten from each horse;

- hoof solar length to height at withers;
- hoof width to height at withers;
- hoof solar length to chest circumference;
- hoof width to chest circumference;
- hoof solar length to body length;
- hoof solar width to body length;
- hoof index (HI=SW/SL×100), (where SW is solar width and SL is solar length)

Statistical Analysis

Utilizing the Shapiro-Wilk test, the data sets were evaluated for normality and thereafter subjected to independent sample T test or Mann-Whitney U test to compare the parameters between the shod and the barefooted horses. The relationship between the hoof and body parameters were evaluated using Pearson's Bi-variate correlation analysis. One way analysis of variance (ANOVA) was used to assess the variations in hoof parameters among the limbs followed by Turkey Kramer Post Hoc test. The results were considered statistically significant if $P \leq 0.05$. The statistical analysis was carried out using the Statistical Package for Social science (SPSS version 25) software.

RESULTS

A total of thirty-four (34) female Sudanese country bred horses were examined. All the horses were intact. Thirty-two (94%) were housed on concrete floor, while 2 (6%) were on non-concrete floor. Thirteen (38%) of the horses were shod, while twenty-one (62%) were barefooted. A review of the horses' past diets revealed that all of them were fed grass, wheat bran, and finished feed; none of them received any supplements. The health history of the horses showed that 12 (35.3%) had previous colic, 9 (26.5%) had previous history of lameness, 3 (9.2%) had previous illnesses while 10 (29%) horses had previous body injury. Method of treatment of body injury used included massage and bandaging (13; 65%), local herb (3; 15%), petrol (2; 10%) and fiberglass cast (1; 5%).

Body indices of Sudanese country-bred mares.

The mean height of the horses was 1589.5 ± 56.0 mm (1470mm – 1720 mm), the mean body weight of the horses was 430.8 ± 42.9 kg (353kg – 529 kg) while the mean heart girth was 1758.8±65.31mm (1630-1900mm). Also, the mean body length of the horses was 1649.4±50.03mm (1560-1740mm). There was no significant difference in the body traits between the shod and barefooted Sudanese country-bred horses (Table 1).

Effect of shoeing on Hoof morphometry in Sudanese country-bred mares.

Between the shod and barefoot Sudanese country-bred horses, there was a statistically significant difference ($p<0.05$) in the dorsal hoof wall width, hoof solar length, and hoof solar width (Table 2). Nonetheless, there was no statistically significant difference ($p>0.05$) between the shod and barefoot Sudanese country-bred horses in terms of toe length or ventral hoof wall width.

Table 1: Body traits between shod and barefooted Sudanese country-bred mares.

Body trait	Shoeing	Mean±SD	P-value
HEIGHT (mm)	Shod	1605.38±61.86	0.198
	Barefooted	1579.67±51.13	
HEARTGIRTH	Shod	1742.31±75.07	0.252
	Barefooted	1769.05±58.04	
BODYLENGTH	Shod	1645.38±66.41	0.718
	Barefooted	1651.90±38.29	
BODYWEIGHT	Shod	422.23±51.85	0.367
	Barefooted	436.14±36.86	

*pvalue is significant at $p<0.05$

Pearson's correlation between body indices of Sudanese country-bred mares.

Regarding Sudanese country-bred mares, there was a strong positive statistical correlation between body weight, body length, and heart-girth. The Bodyweight and heartgirth (r=0.981; p=0.001), Body length and body weight (r=0.874; p=0.001), body length and height(r=0.465; p=0.01), heart girth and height (r=0.401; p=0.01),height and bodyweight (r=0.447; p=0.01) as well as body length and heart girth (r=0.768; p=0.001) all showed positive correlations.

Pearson's correlation between body indices and hoof parameters of the fore and hind limbs in Sudanese country-bred mares.

Height and hoof solar width, dorsal hoof wall width, and ventral hoof wall width were found to be positively correlated, whereas toe length was positively correlated with heart-girth and body weight in the forelimbs (Table 3). Height, hoof solar width, and dorsal hoof wall width all exhibited a positive correlation in the hind limbs, whereas body weight and heart girth showed a positive correlation with hoof solar length (Table 4). However, there was negative correlation, although not statistically significant between other body indices and fore and hind limbs hoof parameters.

Effects of shoeing on hoof traits to body indices ratio of Sudanese country-bred mares.

The hoof solar length to height ratio, the hoof solar length to heart-girth ratio, and the hoof solar length to body length ratio (Figure 2) between the shod and barefooted horses were all statistically significantly different ($p<0.05$) (Table 5). Furthermore, a statistically significant difference ($p<0.05$) was observed in the ratio of the hoof solar width to body indices in nearly every limb between the horses that were shod and those that were barefoot (Table 6). Concurrently, the hoof index of the shod and barefoot horses differed statistically significantly ($p<0.05$) (Table 7).

Difference between fore and hind limb hoof morphometry.

The measurements of the left and right forelimbs and hind limbs did not differ significantly; however, the forelimb's solar width and length of hoof were significantly greater than those of the hind limb (Table 8).

Table 2: Hoof traits between shod and barefooted Sudanese country-bred mares

HOOF TRAITS		Minimum	Maximum	Mean±SD	P-value
HSWLF	Shod	114.00	137.00	123.1±6.67	0.040*
	Barefooted	100.9	129.5	117.4±8.11	
HSWRF	Shod	81.7	132.5	119.6±12.52	0.120
	Barefooted	81.7	128.6	115.8±10.40	
HSWLH	Shod	103.2	127.6	116.9±7.19	0.065
	Barefooted	94.4	126.3	112.0±9.05	
HSWRH	Shod	105.3	126.7	118.3±6.45	
	Barefooted	94.2	12 6.7	112.5±8.86	0.037*
HSLLF	Shod	100.3	124.2	112.7±6.60	0.090
	Barefooted	103	134.1	117.4±8.09	
HSLRF	Shod	95.4	138.9	110.2±11.10	0.108
	Barefooted	95.4	131.2	115.82±8.58	
HSLLH	Shod	102.8	127.4	108.4±6.78	0.006*
	Barefooted	103.6	128.7	115.48±6.59	
HSLRH	Shod	91.3	121	107.98±7.95	0.003*
	Barefooted	102	128.1	116.81±7.52	
TLLF	Shod	80.20	103.5	87.14±7.18	0.481
	Barefooted	64.6	106.8	84.63±11.33	
TLRF	Shod	39.4	107.8	82.84±16.99	0.624
	Barefooted	40	121.5	84.46±15.58	
TLLH	Shod	71	99.3	85.93±9.03	0.933
	Barefooted	65.4	99.20	85.66±8.92	
TLRH	Shod	55.90	114.20	87.12±13.46	0.991
	Barefooted	71.40	114.80	87.16±10.36	
DHWWLF	Shod	260	360	302.31±27.74	0.011*
	Barefooted	220	310	280.48±19.62	
DHWWRF	Shod	260	310	290.77±18.47	0.110
	Barefooted	240	305	280±18.64	
DHWWLH	Shod	260	350	290±22.36	0.060
	Barefooted	240	330	277.14±19.78	
DHWWRH	Shod	270	340	288.85±18.95	0.035*
	Barefooted	230	310	273.57±20.07	
VHWWLF	Shod	50	70	60±4.08	0.400
	Barefooted	40	80	58.1±8.73	
VHWWRF	Shod	50	70	59.62±5.19	0.462
	Barefooted	40	90	58.1±11.23	
VHWWLH	Shod	50	80	61.52±8.01	0.753
	Barefooted	50	80	60.47±8.05	
VHWWRH	Shod	50	70	63.08±6.30	0.506
	Barefooted	50	80	60.95±9.44	

*Value significance at $p \leq 0.05$

Keys: HSWLF: Hoof Solar Width of Left Fore limb; **HSWRF**: Hoof Solar Width of Right Fore limb; **HSWLH**: Hoof Solar Width of Left Hind limb; **HSWRH**: Hoof Solar Width of Right Hind limb; **HSLLF**: Hoof Solar Length of the Left Fore limb; **HSLRF**: Hoof Solar Length of the Right Fore limb; **HSLLH**: Hoof Solar Length of the Left Hind limb; **HSLRH**: Hoof Solar Length of the Right Hind limb; **TLLF**: Toe length of the Left Fore limb; **TLRF**: Toe length of the Right Fore limb; **TLLH**: Toe length of the Left Hind limb; **TLRH**: Toe length of the Right Hind limb; **DHWWLF**: Dorsal Hoof Wall Width of the Left Fore limb; **DHWWRF**: Dorsal Hoof Wall Width of the Right Fore limb; **DHWWLH**: Dorsal Hoof Wall Width of the Left Hind limb; **DHWWRH**: Dorsal Hoof Wall Width of the Right Hind limb; **VHWWLF**: Ventral Hoof Wall Width of the Left Fore limb; **VHWWRF**: Ventral Hoof Wall Width of the Right Fore limb; **VHWWLH**: Ventral Hoof Wall Width of the Left Hind limb; **VHWWRH**: Ventral Hoof Wall Width of the Right Hind limb

DISCUSSION

In addition to helping horse owners assess the financial losses, hoof morphometry offers crucial information that can be used to perform precise trimming, shoeing, and hoof soundness assessments (Kawareti *et al.,* 2017a). Several morphometric or radiographic measurement of the hoof have been reported in horses of different breed, sex and age groups (Clayton *et al.,* 2011; Stachurska *et al.,* 2011; Souza *et al.,* 2016; Kawareti *et al*., 2017b; Lesniak *et al.,* 2017; Ogbanya *et al.,* 2017; Vali and Bazyari, 2018; Souza *et al.,* 2020; Sellke *et al.,* 2023). However, none has reported the hoof morphometry in Sudanese country-bred mare. According to reports, there is sex preference when it comes to using horses: mares are preferred for polo, racing and showjumping, while

males are preferred for dressage (Aune *et al.,* 2020). The preference for female horses in polo game might also be because female horses might be easier to control than the male horses. This study was solely on female Sudanese country-bred horses because they were abundant and available during the study.

The heart girth and body length measurements have a strong correlation with body weight in the present study. The association between heart girth, body length and body weight as used in weight estimation in the present study has been reported to be the accurate way to estimate body weight in many breeds of horses (Carroll and Huntington 1988). Toe length, hoof width and hoof length are like other breeds of horses (Stachurska *et al.,* 2008; Clayton *et al.,* 2011; Souza *et al.,* 2016; Kawareti *et al.,* 2017, Souza *et al.,* 2020). This study demonstrates a significant variation in hoof dimensions between shod and barefooted horses. According to a prior study (Stutz *et al.,* 2018), the presence of shoes was found to significantly alter over 75% of the spatiotemporal variables examined in shod horses as opposed to barefooted horses, as well as hoof shape, morphology, and measurement (Clayton *et al.,* 2011; Lesniak *et al.,* 2017, Malone and Davies, 2019).The effects of shoeing in horses breed have been evaluated especially in relation to hoof morphology (Clayton *et al.,* 2011), limb kinematics and kinetics (Willemen *et al.,* 1997; Singleton *et al.,* 2003) and proprioception (Bowker *et al.,* 1993). Findings from some of these studies revealed some potentially deleterious effects on horse shoeing on hoof soundness. These contribute to the justification for advocating for barefoot horses and advancing the wellbeing of their unshod hooves (Strasser, 2000). Nonetheless, the fact that an unshod hoof deforms in reaction to loading during the stance phase, whereas shoeing restricts hoof deformation and bulb expansion, is a significant argument in favor of shoeing performance horses (Roepstorff *et al.,* 2001; Van Heel *et al.,* 2004). In equine orthopaedics, trimming and shoeing are still crucial problems (Hood *et al.,* 2001, Kummer *et al.,* 2006). Of the horses with forelimb lameness, 72.8% have malalignment of the digital bones (Page and Hagen, 2002). The hoof's outer wall, sole, frog, bones, cartilage, tendons, and blood supply all play a crucial part in helping the animal maintain its weight. Breed-to-breed variations in hoof size notwithstanding, the fundamental form and structure remain the same (Butler *et al.,* 1993).

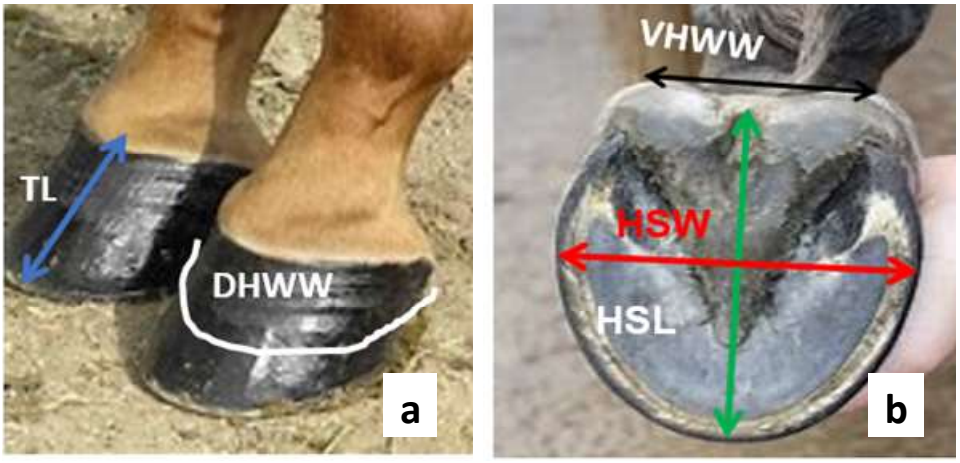

Table 3: Pearson's correlation coefficient of body traits to hoof parameters of left and right forelimbs Sudanese country-bred horses.

	Hoof solar width		**Hoof solar length**		**Toe length**		**Dorsal hoof wall width**		**Ventral hoof wall width**	
	Lfl	Rfl	Lfl	Rfl	Lfl	Rfl	Lfl	Rfl	Lfl	Rfl
H	.45*	.40*	0.14	-0.01	0.07	0.12	.438*	0.23	.36*	.40*
HG	-0.12	0.32	-0.07	0.22	-0.11	.38*	-0.084	-0.15	0.07	0.09
BL	-0.01	0.27	-0.17	-0.01	-0.14	0.29	-0.073	-0.17	0.04	0.03
BW	-0.08	0.31	-0.1	0.15	-0.11	.36*	-0.069	-0.16	0.07	0.09

*Pearson's correlation coefficient is statistically significant at <0.05

Key: **Lfl:** Left forelimb; **Rfl:** Right forelimb; **H:** height; **HG:** Heart girth; **BL:** body length; **BW:** Bodyweight

Table 4: Pearson's correlation coefficient of body traits to hoof parameters of left and right hind limbs of Sudanese country-bred horses

	Hoof solar width		**Hoof Solar length**		**Toe length**		**Dorsal hoof wall width**		**Ventral hoof wall width**	
	Lhl	Rhl	Lhl	Rhl	Lhl	Rhl	Lhl	Rhl	Lhl	Rhl
H	.41*	0.30	0.22	0.10	-0.00	0.01	.46*	.34*	0.28	0.21
HG	-0.10	-0.23	.46*	.36*	-0.09	-0.13	-0.11	-0.17	0.05	-0.11
BL	0.07	-0.07	0.34	0.14	-0.04	-0.17	0.03	0.02	-0.04	-0.18
BW	-0.04	-0.18	.44*	0.32	-0.07	-0.14	-0.06	-0.11	0.05	-0.13

*Pearson's correlation coefficient is statistically significant at <0.05

Key: **Lfl:** Left forelimb; **Rfl:** Right forelimb; **H:** height; **HG:** Heart girth; **BL:** body length; **BW:** Bodyweight

Table 5: Hoof Solar Length to Body trait ratios between shod and barefooted Sudanese country-bred horses.

HOOF RATIOS		M±SD	P value (<0.05)
HSL.H.RFL	Shod	0.068±0.005	0.005*
	Barefooted	0.074±0.004	
HSL.H.LFL	Shod	0.071±0.006	0.132
	Barefooted	0.074±0.004	
HSL.H.RHL	Shod	0.068±0.005	0.001*
	Barefooted	0.074±0.005	
HSL.H.LHL	Shod	0.067±0.003	0.000*
	Barefooted	0.074±0.004	
HSL.HG.RFL	Shod	0.063±0.008	0.168
	Barefooted	0.064±.004	
HSL.HG.LFL	Shod	0.062±0.006	0.755
	Barefooted	0.066±0.005	
HSL.HG.RHL	Shod	0.062±0.005	0.088
	Barefooted	0.066±0.004	
HSL.HG.LHL	Shod	0.061±0.003	0.029*
	Barefooted	0.065±0.004	
HSL.BL.RFL	Shod	0.066±0.008	0.060
	Barefooted	0.069±0.004	
HSL.BL.LFL	Shod	0.066±0.006	0.839
	Barefooted	0.068±0.005	
HSL.BL.RHL	Shod	0.063±0.006	0.025*
	Barefooted	0.070±0.005	
HSL.BL.LHL	Shod	0.064±0.003	0.003*
	Barefooted	0.068±0.004	

*Value is significant at p≤0.05

Key: HSL.H.RFL: Hoof Solar Length ratio Height in the Right fore Limb; **HSL.H.LFL**: Hoof Solar Length ratio Height in the Left Fore Limb; **HSL.H.RHL**: Hoof Solar Length ratio Height in the Right Hind Limb; **HSL.H.LHL**: Hoof Solar Length ratio Height in the Left Hind Limb; **HSL.HG.RFL**: Hoof Solar Length ratio Heartgirth in the Right Fore Limb; **HSL.HG.LFL**: Hoof Solar Length ratio Heartgirth in the Left Fore Limb; **HSL.HG.RHL**: Hoof Solar Length ratio Heartgirth in the Right Hind Limb; **HSL.HG.LHL**: Hoof Solar Length ratio Heartgirth in the Left Hind Limb; **HSL.BL.RFL**: Hoof Solar Length ratio Body length in the Right fore Limb; **HSL.BL.LFL**: Hoof Solar Length ratio Body length in the Left Fore Limb; **HSL.BL.RHL**: Hoof Solar Length ratio Body length in the Right Hind Limb; **HSL.BL.LHL**: Hoof Solar Length ratio Body length in the Left Hind Limb

Table 6: Hoof Solar Width to Body trait ratios between shod and barefooted Sudanese country-bred horses

HOOF RATIOS		M±SD	Pvalue (<0.05)
HSW.H.RFL	Shod	0.073±0.010	0.785
	Barefooted	0.074±0.004	
HSW.H.LFL	Shod	0.078±0.004	0.008*
	Barefooted	0.073±0.004	
HSW.H.RHL	Shod	0.076±0.004	0.001*
	Barefooted	0.070±0.004	
HSW.H.LHL	Shod	0.074±0.004	0.008*
	Barefooted	0.070±0.005	
HSW.HG.RFL	Shod	0.068±0.009	0.272
	Barefooted	0.066±0.004	
HSW.HG.LFL	Shod	0.073±0.004	0.000*
	Barefooted	0.065v0.004	
HSW.HG.RHL	Shod	0.070±0.004	0.000*
	Barefooted	0.062±0.004	
HSW.HG.LHL	Shod	0.070±0.004	0.000*
	Barefooted	0.062±0.005	
HSW.BL.RFL	Shod	0.072±0.010	0.560
	Barefooted	0.071±0.004	
HSW.BL.LFL	Shod	0.076±0.004	0.001*
	Barefooted	0.070±0.004	
HSW.BL.RHL	Shod	0.074±0.004	0.000*

	Barefooted	0.067±0.004	
HSW.BL.LHL	Shod	0.072±0.003	0.000*
	Barefooted	0.066±0.005	0.000*

*Value is significant at p≤0.05

Key: HSW.H.RFL: Hoof Solar Length ratio Height in the Right fore Limb; **HSW.H.LFL:** Hoof Solar Length ratio Height in the Left Fore Limb; **HSW.H.RHL:** Hoof Solar Length ratio Height in the Right Hind Limb; **HSW.H.LHL:** Hoof Solar Length ratio Height in the Left Hind Limb; **HSW.HG.RFL:** Hoof Solar Length ratio Heart girth in the Right Fore Limb; **HSW.HG.LFL:** Hoof Solar Length ratio Heartgirth in the Left Fore Limb

HSW.HG.RHL: Hoof Solar Length ratio Heartgirth in the Right Hind Limb; **HSW.HG.LHL:** Hoof Solar Length ratio Heartgirth in the Left Hind Limb; **HSW.BL.RFL:** Hoof Solar Length ratio Body length in the Right fore Limb; **HSW.BL.LFL:** Hoof Solar Length ratio Body length in the Left Fore Limb; **HSW.BL.RHL:** Hoof Solar Length ratio Body length in the Right Hind Limb; **HSW.BL.LHL:** Hoof Solar Length ratio Body length in the Left Hind Limb

Table 7: Hoof Index between shod and barefooted Sudanese country-bred horses

HOOF RATIOS		**M±SD**	**P value(p<0.05)**
SW.SL.100.RFL	Shod	108.883±13.179	0.013*
	Barefooted	100.148±6.158	
SW.SL.100.LFL	Shod	109.803±6.478	0.000*
	Barefooted	99.907±5.118	
SW.SL.100.RHL	Shod	112.425±8.427	0.000*
	Barefooted	95.244±8.543	
SW.SL.100.LHL	Shod	110.945±4.360	0.000*
	Barefooted	94.867±7.642	

*Value significant at p≤0.05

Table 8: Hoof parameters between the left and right limb, fore and hind limb of Sudanese country-bred horses

	RFL	**LFL**	**RHL**	**LHL**
HSW	120.28±11.23*	119.57±7.10*	114.71±8.41	113.43±8.73
HSL	118.91±14.66*	117.86±7.84*	113.43±8.73	112.78±7.58
TL	83.84±15.90	85.31±10.29	87.14±11.44	85.31±10.29
DHWW	284.12±19.05	288.06±21.43	279.41±20.77	282.60±21.43
VHWW	58.68±9.32	58.82±7.29	61.76±8.34	60.88±7.93

*Value significant at p≤0.05

Key: HSW: Hoof Solar Width; **HSL**: Hoof Solar length; **TL:** Toe length; **DHWW**: Dorsal Hoof wall width; **VHWW**: Ventral hoof wall width; **RFL**: right forelimb; **LFL:** left forelimb; **RHL;** right hind limb; **LHL**: left hind limb

The size of the animal and the size of its hoof are highly correlated (Melo *et al.,* 2006). Balch *et al.* (1991) proposed a relationship that limits the maximum toe length based on the weight category. This relationship is between the toe length and live weight. There were both positive and negative correlation between hoof parameters and body indices. This shows the body indices measured in the present study has effect on the hoof morphometry. While height at withers has no positive correlation with hoof measurement, Lesniak *et al.* (2019) found a positive correlation between body weight and hoof solar width in the left and right forelimb of horses. This finding contradicts the findings of this study.

The hoof measurements of the left and right forelimbs and hind limbs did not significantly differ from one another. This aligns with the findings of studies conducted by Stachurska *et al.* (2008) and Souza *et al.* (2020). The hoof solar width and length of the forelimb, however, were significantly greater than those of the hind limb, in line with a prior report (Stachurska *et al.,* 2008; Melo *et al.,* 2011; Casanova and Oosterlinck 2012; Sampaio *et al.,* 2013; Kawareti *et al.,* 2017; Souza *et al.,* 2020). This larger forelimb hoof solar surface suggests that the forelimb hoof will have excellent landing support, stabilizing the body weight during landing (Kawareti *et al.,* 2017). The hoof solar length and width is similarly different between shod and barefooted horses thus suggesting a barefooted horse having more stability during landing than a shod horse. There was reduced palmar hoof expansion when the hoof was shod or elevated from the surface using the hoof wall as support (Caldwell, 2017).

Hoof and body dimensions ratios evaluated in the present study were carried out to determine the relative hoof size. The growth of hoof rapidly increases from birth up to six years of age and then grow slowly with older horses having a relatively little difference in hoof size unlike younger horses (Stachurska *et al.,* 2011). The hoof index obtained during this investigation is consistent with the findings of Stachurska *et al.,* (2008). The horses' height at withers and the dimensions of their hooves were significantly more correlated. This differs from the study of Stachurska *et al.,* (2011) who reported high correlation between the chest circumference and hoof parameters. Nonetheless, Kummer *et al.,* (2005) discovered a few weakly positive correlations between the horses' height at withers and the hoof parameters. In the present study, hoof width is highly correlated with the body size measurement in both fore and hind limb. With the hoof width being the most characteristic dimension of the hoof (Stachurska *et al*. 2008). Also, the hoof width to body measurement ratios as well as Hoof index were most significant ratios of the relative hoof size. This is like the study of Stachurska *et al.*, (2011). It can therefore be suggested that hoof width to body measurement and hoof

index ratio are relative measure of the hoof size in Sudanese country-bred horses.

Regarding the shod and the barefooted, all ratios relating the hoof dimensions to the wither's height, chest circumference, and body length varied. Most differences in the ratios between the shod and unshod where significant Bilateral hoof symmetry is important in facilitating even mass distribution (Lesniak *et al.* 2019). The left and right hoof measurements showed a positive correlation, suggesting that the left and right fore and hind limbs had similar increases in hoof measurement. Despite the theory that hooves exhibit distinct individual conformation and asymmetries (Wilson *et al.,* 2009), symmetry and regularity are important criteria for judging overall gait quality and, consequently, for dressage performance (Bystrom *et al.,* 2018). This may be in the hoof kinetics and kinematics rather than morphometry

Conclusion

According to this study, Sudanese Country-bred horses' hoof morphometry is significantly impacted by shoeing and body indices. The left and right forelimbs' hoof dimensions were symmetrical, but the forelimb and hind limbs dimensions were asymmetrical, with the forelimb's hoof solar width and length being noticeably greater than those of the hind limb. It can therefore be suggested that hoof width to body measurement and hoof index ratio are relative measure of the hoof size in Sudanese country-bred horses. This is the first study to describe the morphometric differences in hoof shape between Sudanese Country-bred horses that are shod and those that are barefooted. A deeper comprehension of the variables influencing hoof shape could result in improved hoof care techniques that reduce the possibility of horse injury.

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Conflict of Interest

The authors have no conflict of interest to declare.

Authors' Contribution

OIO, ARA conceptualized the idea and designed the study, OIO, SSA, KSA carried out the research and analyzed the data. OIO and SSA wrote the manuscript. All authors reviewed, read, and approved the final manuscript.

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