

Patterns of indigenous female cattle morphometric traits variations in Uganda: Evidence for farmers' selection to enhance agro-ecological fitness

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Summary

Globally, rural cattle keeping communities actively select and breed indigenous cattle to satisfy their interests and enhance adaptation to local landscapes. This study investigated how traditional systems in Uganda have shaped the morphometric population structure of indigenous cattle breeds. Ten linear morphometric traits were interrogated amongst 801 female cattle, comprising 46 Nganda (*Bos indicus*), 368 Ankole (*B. taurus indicus*) and 387 East African shorthorn zebu (EASZ, *B. indicus*). The study cattle were obtained evenly at random from 209 herds in their agro-ecological zones (AEZs) where they have been nurtured by traditional cattle keeping communities throughout Uganda. Age, AEZs and breed significantly influenced the variation of linear morphometric traits exhibiting a gradient of low, intermediate and high dimensions among the EASZ, Nganda and Ankole cattle, respectively. Likewise, the linear morphometric trait (Mahalanobis squared distance) diversity was significantly different exhibiting a gradient of low, intermediate and high variation between Nganda and EASZ, Ankole and Nganda, and Ankole and EASZ cattle, respectively. These findings demonstrate the role of agro-ecological fitness in the evolution of indigenous cattle morphometric population structure in Uganda. The study outcomes further provide a motivation to search for genes associated with the diverse morphometric features.

Keywords: *adaptation, agro-ecological fitness, female indigenous cattle, linear morphometric trait variation, Uganda*

Résumé

Globalement, le bétail ruraux en gardant les communautés sélectionner activement et élèvent du bétail autochtones à satisfaire leurs intérêts et améliorer l'adaptation aux paysages locaux. Cette étude a examiné comment les systèmes traditionnels en Ouganda ont façonné la structure de la population morphométrique des races bovines autochtones. Dix traits morphométriques linéaires ont été interrogés entre 801 bovins femelles, comprenant 46 Nganda (*Bos indicus*), 368 Ankole (*B. taurus indicus*) et 387 East African Shorthorn Zébu (EASZ, *B. indicus*). Les bovins de l'étude ont été obtenus uniformément au hasard à partir de 209 troupeaux dans leurs zones agro-écologiques (ZAE) où ils ont été nourris par l'élevage traditionnel de maintien de communautés à travers l'Ouganda. Âge, ZAE et élever significativement influencé la variation de traits morphométriques linéaires présentant un gradient de dimensions faibles, intermédiaires et élevés chez les EASZ, Nganda et Ankole bétail respectivement. De même, le caractère linéaire morphométrique (Mahalanobis distance au carré) la diversité est significativement différente présentant un gradient de faible, moyenne et forte variation entre Nganda et EASZ, Ankole et Nganda, Ankole et bétail EASZ respectivement. Ces résultats démontrent le rôle de remise en forme agro-écologique dans l'évolution de la structure de la population des bovins morphométrique indigène en Ouganda. Les résultats fournissent en outre une motivation à rechercher des gènes liés aux caractéristiques morphométriques diverses.

Mots-clés: *L'adaptation, Remise en forme agro-écologique, Bovins indigènes des femmes, La variation des caractéristiques morphométriques, Ouganda*

Resumen

En todos los países del Mundo, las comunidades rurales de ganaderos seleccionan activamente y crían el ganado bovino autóctono con el fin de satisfacer sus intereses y de mejorar la adaptación al entorno local. Este estudio pretendió determinar de qué manera los sistemas tradicionales han conformado, en Uganda, la estructura morfométrica de la población de razas bovinas autóctonas. Se midieron diez rasgos morfométricos lineales en 801 hembras de ganado bovino, entre las cuales 46 de raza Nganda (*Bos indicus*), 368 de raza Ankole (*B. taurus indicus*) y 387 de Cebú de Cuernos Cortos del Este de África (EASZ por sus siglas en inglés, *B. indicus*). Los animales del estudio fueron tomados, por toda Uganda, equitativamente y al azar, de 209 rebaños, en las zonas agroecológicas en las que habían sido criados por comunidades tradicionales de ganaderos. La edad, la zona agroecológica y la raza influyeron significativamente sobre la variación de los rasgos morfométricos lineales, mostrando un gradiente de bajo, intermedio y alto en las medidas para el ganado EASZ, Nganda y Ankole, respectivamente. Asimismo, la diversidad en los rasgos morfométricos lineales (distancia cuadrática de Mahalanobis) difirió significativamente, mostrando un gradiente de bajo, intermedio y alto para la variación entre

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Nganda y EASZ, entre Ankole y Nganda y entre Ankole y EASZ, respectivamente. Estos resultados demuestran el papel de la adaptación a la zona agroecológica en la evolución de la estructura morfométrica de la población de ganado bovino autóctono en Uganda. Lo hallado en este estudio anima a buscar los genes asociados con las diversas características morfométricas.

Palabras clave: *Palabras clave, adaptación, encaje en la zona agroecológica, hembras de ganado bovino autóctono, variación en los rasgos morfométricos lineales, Uganda*

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Introduction

The Ministry of Agriculture, Animal Industry and Fisheries (MAAIF), and the Uganda Bureau of Statistics (UBOS, 2009) reported the population of indigenous cattle to be 10.64 million, spread throughout the country's agro-ecological zones (AEZs). The key indigenous cattle breeds comprise the Ankole (*Bos taurus indicus*) and EASZ (*Bos indicus*), although several variations of these two occur, named in respect of their keepers such as the Nganda, Nyoro, Karamojong and Nkedi breeds (Balikowa, 2011). The Ankole are present in the western and southwestern (Ndumu *et al.*, 2008b; Kugonza *et al.*, 2011), while the EASZ cattle are established in the eastern, northeastern, northern and west Nile regions of Uganda (MAAIF/UBOS, 2009; Balikowa, 2011). Several regions in central Uganda exhibit composite breeds between the Ankole, EASZ and Friesians giving rise to various grades of cross-bred cattle such as the Nganda, Nkedi, Serere, Nsoga and Kyoga (Bett *et al.*, 2013). They provide livelihoods to 26.1 percent of all households in Uganda through delivery of several goods and amenities as described by Kugonza *et al.* (2011); Hanotte, Dessie and Kemp (2010); Food and Agricultural Organisation of the United Nations (FAO, 2009). In addition, they facilitate sustainable utilization of marginal resources where no other type of agricultural investment is possible (Anderson, 2003; FAO, 2007). This is because indigenous cattle have become tolerant to endemic infections and have the ability to live on poor quality feed resources (Scarpa *et al.*, 2003; Taberlet *et al.*, 2008; Rege *et al.*, 2011). In this report, adaptation is used to refer to anatomical, physiological or behavioural traits that contribute to an individual's ability to survive and reproduce ("fitness") in an environment which it has evolved (Lamy *et al.*, 2012).

Local farmers exploit indigenous cattle adaptive traits to selectively breed for agro-ecological fitness and socio-cultural identity (Ndumu *et al.*, 2008a; FAO, 2009). Consequently, selective breeding has resulted into the evolution of undefined diverse indigenous cattle morphometric population structures (Ndumu *et al.*, 2008a, 2008b). These morphometric variations signify diversity and constitute appropriate genetic resources for future generations (Hoffmann, 2010) which deserve adequate conservation efforts. Present national policies favour the utilization of industrial cattle breeds for higher productivity to meet the increasing population food demands (MAAIF, 2012; Galukande *et al.*, 2013). But exotic breeds have inadequate adaptive agro-ecological fitness compared with

indigenous cattle (Scarpa *et al.*, 2003) and therefore require more resource inputs to thrive under the local tropical conditions. Present policies aiming at higher productivity put local cattle genotypes at risk of obliteration (Taberlet *et al.*, 2008; Wilson, 2009). Knowledge of morphometric variation is useful for making inferences about farmers' roles in the evolution of indigenous livestock morphological diversity, landscape fitness and adaptation (Mwacharo *et al.*, 2006; Kugonza *et al.*, 2011). For example, smaller and stout body frames have evolved to enhance long-distance trekking and survival on scarce, less nutritive feed resources (Loquang and Köhler-Rollefson, 2005; FAO, 2007; Nalule, 2010; Herrero *et al.*, 2012).

Studies of indigenous cattle morphometric diversity in the different AEZs constitute an initial step in conservation of genetic resources and can be a basis for genetic improvement programmes. Additionally, body morphometric traits and adaptive features are useful for identification of breed qualities relevant to livestock farming community utility needs. The current advocacy for sustainable agricultural systems favours well-evolved local breed types as future candidates for conservation and utilization. Modern techniques have now enabled the association of such traits with the genotypes enhancing the application of genetic marker-assisted selection with conservation of adaptive traits (Zhang and Li, 2011). Presently, Uganda's indigenous cattle morphometric population structure is partly described. The main objectives of this study were: (1) to establish nationwide indigenous cattle morphometric structure associated with AEZs and farmers' selective breeding practices; (2) to provide support to upcoming improvement and conservation schemes; and (3) to provide basic information for genome wide association studies (GWAS).

Materials and methods

Study area

This study covered the whole of Uganda due to the widespread distribution of indigenous cattle. The study area has been described in Kabi *et al.* (2014). Briefly, Uganda's total area is 241 550.7 square kilometres (sq. km), with open waters and land occupying 41 743.2 and 199 807.4 sq. km, respectively. The county's altitude ranges from 620 m (Albert Nile) to 5 111 m (Mt. Rwenzori peak) above sea level. The temperatures range from 16 to 26 °C (April and November) and over 30 °C (December and

March) in most regions. Southern Uganda receives more rainfall (>2 100 mm), which decreases towards the north and northeast (<500 mm) turning into semi-arid conditions. These conditions influence the occurrence of well-vegetated savannah in western, southern and central regions, while dry plains occur in northern and north-eastern regions of Uganda (UBOS, 2013). Several lakes and rivers occur, which influence the availability of natural pasture and water on which indigenous cattle systems entirely depend. Uganda's 10 AEZs have been described (Figure 1) as areas with homogeneous socio-economic, ecological and farming systems (MAAIF, 2004). They include the northeastern drylands (NED), northeastern savannah grasslands (NESG), northwestern savannah grasslands (NWSG), Kyoga Plains (KP), Lake Victoria Crescent (LVC), western savannah grasslands (WSG), western highland ranges (WHR), pastoral rangelands (PR), southwestern farmlands (SWF) and para savannahs (PS). Different indigenous cattle breeds are reared in all the AEZs, preferred for their tolerance to endemic tick-borne diseases and ability to survive on poor quality feeds (MAAIF/UBOS, 2009).

Data collection procedure

This study embraced a landscape sampling strategy defined by 50 grid cells, enabling an inclusive sampling across the 10 AEZs as previously explained in Kabi *et al.* (2014). Only female cattle were used in this study due to the low numbers of males available in the sampled herds. Ten linear morphological traits were measured from 801 randomly selected female cattle from 209 herds comprising 46 Nganda (*B. indicus*), 368 Ankole (*B. taurus indicus*) and 387 EASZ (*B. indicus*). The Nganda sample size was quite low compared with other breed groups, however, they were considered due to the fact they are reared within crop-livestock localities and are regarded as *B. indicus* with unique attributes. An Etrex[®] global positioning system (GPS) handset device which employs satellite navigation system was used for recording the topographical positions of the different sample farms/herds. Locations (latitudes and longitudes) of the 209 were overlaid on the 10 AEZ using ArcGIS[®] version 10 to show the countrywide pattern of data collection as shown in Figure 1. Examples of indigenous cattle herds with unique but similar morphological feature and body colour patterns are shown in Figures 2 (a, b) and 3 observed during our field visits.

For each well-restrained female cattle positioned on a relatively even surface, sex, breed, age (months) based on dentition, 10 linear body measurements were recorded to the nearest centimetre (cm) using a flexible tape by the first author to minimize in between-individual variations as previously explained by Mwacharo *et al.* (2006) and Alderson (1999). The linear measurements taken on each animal were:

(a) horn length (HL) – the distance from the base of the horn to its tip,

- (b) animal length (AL) – the distance from the top of the head to the base of the tail,
 (c) fore arm length (FAL) – the distance from the elbow joint to the extreme end of hoof,
 (d) fore arm circumference (FAC) – the perimeter distance of the metacarpal joint of the fore arm,
 (e) face length (FL) – the distance from the muzzle to the top of the head,
 (f) horn base circumference (HBC) – the perimeter distance at the base of the horn,
 (g) length between the horn bases (LHB) – the distance between one horn base to the other,
 (h) length between the horn tips (LHT) – the distance between one horn tip to the other,
 (i) muzzle circumference (MC) – the perimeter distance of the muzzle
 (j) tail length (TL) – the distance from the base of the tail to the end of tail switch.

The measurements were made before the cattle were grazed to avoid ascending biases of certain variables due to feed intake. Gestating females were excluded from this study. The age groups were estimated by dentition and clustered into four categories 7–24, 25–36, 37–72 and 73–192 based on minimal differences observed within the categories.

Statistical analysis

Data coding, cleaning and transformation were done in STATA[®] statistical package (2013). The analyses were performed using the linear regression model of STATA[®] (2013) and Statistical Package for Social Sciences (SPSS) version 21 (IBM[®] SPSS[®] 2012, New York, USA). Means alongside the standard errors (SE) and statistically significant differences between morphological traits based on the study cattle breeds, age groups and AEZs were calculated. Descriptive statistics of the morphometric traits and analysis of variance (ANOVA) were used to establish significant differences at $P \leq 0.05$.

Application of multivariate analysis to interrogate morphometric diversity and classifications of different cattle breeds has recently earned scientific credit (Yakubu, Salako and Imumorin, 2011). Linear statistical regression models to determine the trend of the 10 linear morphometric trait variations among age groups, AEZs and breeds were computed. The linear multiple regression models used took the format of

$$Y_{ijk} = \mu + B_i + AEZ_j + Ak + (BAEZ)_{ij} + (BA)_{jk} + (BAAEZ)_{ijk} + E_{ijk},$$

Y_{ijk} is the morphometric trait on the animal of the i th breed, sampled from the j th AEZ, categorized to the k th age group; μ the overall mean; B_i the effect of the i th breed ($i = \text{Ankole, Nganda, EASZ}$); AEZ_k the effects of the k th AEZ ($k = \text{NED, NESG, NWSG, KP, LVC, WSG, WHR, PR, SWF, PS}$); Al the effect of the l th age group ($l = 7\text{--}24, 25\text{--}36, 37\text{--}72, 73\text{--}192$ months); $(BAEZ)_{jk}$ the

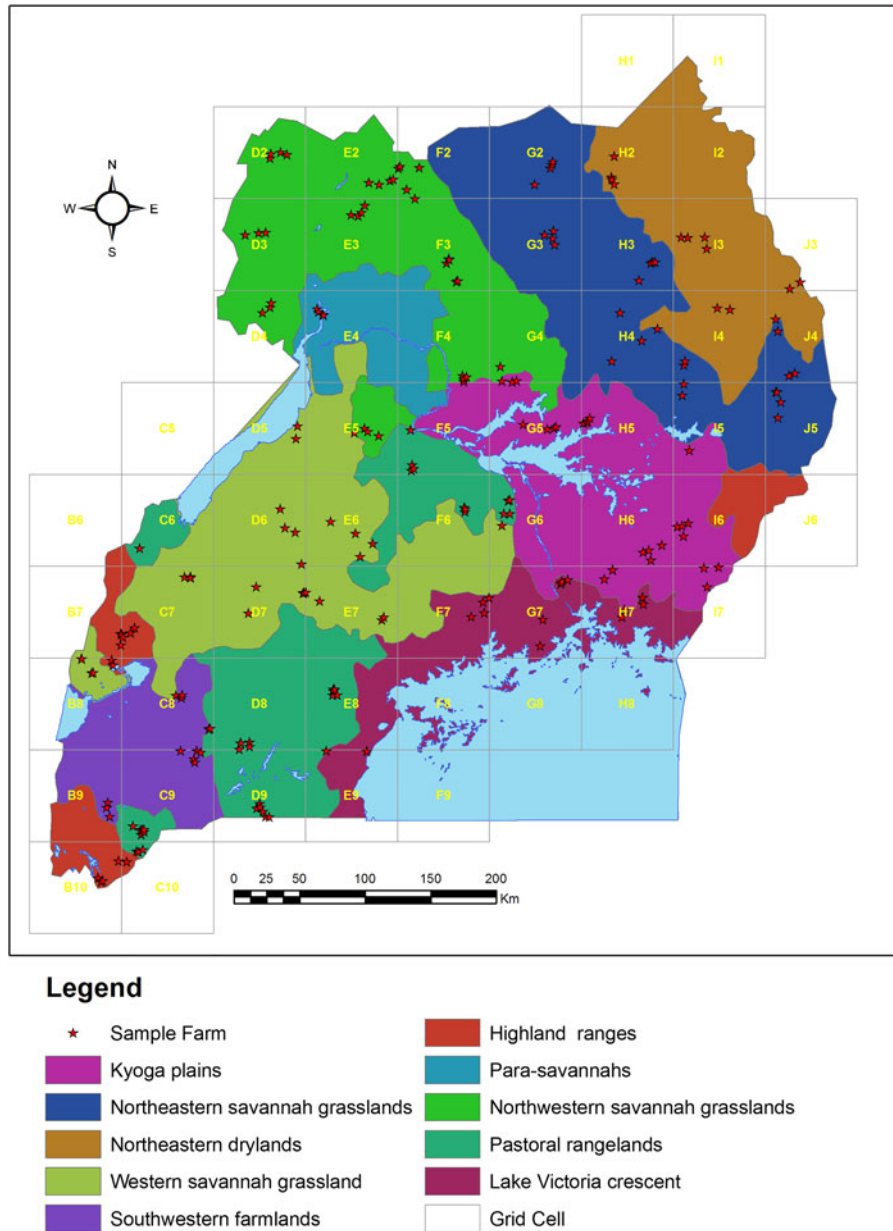


Figure 1. Agro-ecological zones (AEZs) of Uganda (adopted from MAAIF, 2004), grid cells and sampling sites.

interaction effect of the i th breed and k th AEZ; (BAEAZ) ijk the interaction effect of the breed, AEZ, age; and E_{ijk} the random error peculiar to each animal.

Linear regressions coefficients were used to predict the relationships of the 10 linear morphometric traits with the age groups and breed types. The estimated general linear model equation took the format of

$$Y_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5,$$

where Y_i is the morphometric variable; β_0 is the constant coefficient; β_1 to β_5 are the regression coefficients; X_1 and X_2 are the Nganda and EASZ cattle, respectively; X_3 , X_4 and X_5 are the 25–36, 37–72 and 73–192 age groups, respectively.

Mahalanobis squared distances, morphometric classifications were computed in STATA[®] (2013). The stepwise discriminant analysis was performed to determine the most discriminating morphometric trait of the cattle breeds using the SPSS version 21 (IBM[®] SPSS[®] 2012, New York, USA).

Results

Age, breed and AEZs significantly influenced variation of linear morphometric traits of the female cattle studied. Age significantly influenced all traits except HBC, FAL and FAC, while AEZs and breed significantly influenced all the traits. Interactions of breed with AEZs influenced all traits except FAC, while interaction of breed with age,

and AEZs with age significantly influenced FL and FAL, respectively. Interactions of age, breed and AEZs significantly influenced FL only. The summary of ANOVA for the variation of linear morphometric traits and levels of significance are shown in Table 1.

Generally, the study linear morphometric traits exhibited significant gradual increase from low, intermediate to high dimensions among the EASZ, Nganda and Ankole cattle breeds, respectively. All the study traits of Ankole cattle significantly differed among the age groups with exception of HBC. All the study traits of EASZ cattle exhibited significant differences among the age groups with exception of LHB, FAL and FAC. Among the Nganda cattle, the HL, FL, MC and AL exhibited significant differences within the different age groups. The traits generally increased along the age gradient, with older age groups exhibiting higher linear dimensions and providing a suitable source of breed differentiation as shown Table 2.

Linear morphometric traits from SWF, PR and WHR showed comparatively higher dimensions than traits from PS, NED, NESG and NWSG. The variations of morphometric traits within same cattle breeds sampled from different AEZs were observed. Similar traits of Ankole cattle from different AEZs were significantly different. Among the EASZ cattle similar traits exhibited significant differences with exception of LHB, while the LHB, HBC, FAL and MC of Nganda cattle exhibited significant differences as shown in Table 3.

Regression coefficients were used to exhibit the relationship of the 10 linear morphometric traits with breed and age groups. Coefficients of age and breed groups exhibited high levels of significance providing suitable prediction parameters of the linear morphometric traits. For example the HL may be estimated from the following general equation.

$$HL = 44.3 - 26.9X_1 - 42.4X_2 + 4.5X_3 + 12.7X_4 + 20.4X_5,$$

where X_1 and X_2 are the Nganda and EASZ cattle, respectively; X_3 , X_4 and X_5 are the 25–6, 37–72 and 73–192 age groups, respectively. The linear regression coefficients and their levels of significance are shown in Table 4.

Pairwise correlations among the various linear morphometric traits of the three cattle breeds are given in Table 5. Among the Ankole, all the study traits were significantly correlated except for MC versus LHB; whereas among the Nganda, significant correlation were observed in HL versus (LBT, LHT, HBC, FL), LHT versus (LHB, HBC, FL), HBC versus LHB, FL versus HBC, FAL versus (FAC, AL), FAL versus (TL, AL), FL versus (MC, AL), TL versus (MC, AL) and AL versus MC. The EASZ morphometric traits exhibited significant correlations except FAL versus LBT, FAC versus (LBT, LHB, HBC) and MC versus (LHB, HBC, FAL).

Table 1. Summary ANOVA for linear morphometric traits of indigenous female cattle.

Sources of variation	DF	Mean squares and levels of significance for the various linear morphometric traits									
		HL	LHT	LHB	HBC	FAL	FAC	FL	MC	TL	AL
Age	3	6559***	3447**	242*	59 ^{NS}	69 ^{NS}	19 ^{NS}	271***	268***	1031***	9531***
Breed	2	162419***	124961***	5298***	8018***	1739***	741***	1617***	564***	3498***	40950***
AEZ	9	31702***	25609***	1354***	1112***	325***	208***	367***	231***	1193***	8377***
Breed × AEZ	7	5616***	3788***	199***	492***	41***	6 ^{NS}	63***	53***	480***	1170***
Breed × Age	6	975 ^{NS}	282 ^{NS}	73 ^{NS}	38 ^{NS}	12 ^{NS}	11 ^{NS}	25*	21	82	1108***
AEZ × Age	26	647 ^{NS}	707 ^{NS}	70 ^{NS}	99 ^{NS}	22**	9 ^{NS}	16 ^{NS}	7 ^{NS}	58 ^{NS}	475*
AEZ × age × breed	11	486 ^{NS}	518 ^{NS}	36 ^{NS}	78 ^{NS}	7 ^{NS}	8 ^{NS}	24**	10 ^{NS}	160 ^{NS}	169 ^{NS}
Residual	736	373	461	55	64	10	6	9	10	70	278

AEZ, agro-ecological zone; DF, degrees of freedom; EASZ, East African shorthorn zebu; HL, horn length; LHT, length between the horn tips; LHB, length between the horn bases; HBC, horn base circumference; FAL, fore arm length; FAC, fore arm circumference; FL, face length; MC, muzzle circumference; TL, tail length; AL, animal length.

^{NS}, Not significant ($P > 0.05$); ***, very highly significant ($P < 0.001$); **, highly significant ($P < 0.01$); *, significant ($P \leq 0.05$).

Table 2. Variations of linear morphometric traits of indigenous female cattle breeds among the different age groups.

Breed	Age group	n = 801	Morphometric traits (mean ± SE)										
			HL ± SE	LHT ± SE	LHB ± SE	HBC ± SE	FAL ± SE	FAC ± SE	FL ± SE	MC ± SE	TL ± SE	AL ± SE	
Ankole (n = 368)	7–24	17	35.7 ± 5.1 ^a	56.4 ± 5.8 ^a	17.8 ± 1.3 ^c	23.9 ± 2.2 ^{NS}	33.7 ± 0.7 ^b	21.1 ± 0.4 ^b	43.0 ± 1.0 ^a	35.8 ± 0.7 ^a	69.2 ± 2.1 ^a	193.5 ± 3.5 ^a	
	25–36	34	44.0 ± 4.7 ^a	58.1 ± 4.8 ^a	22.1 ± 1.7 ^c	22.3 ± 1.6 ^{NS}	36.3 ± 0.7 ^b	22.4 ± 0.5 ^b	45.8 ± 0.7 ^a	37.2 ± 0.4 ^a	70.0 ± 1.4 ^a	203.8 ± 4.0 ^a	
	37–72	147	56.8 ± 2.3 ^a	69.3 ± 2.3 ^a	21.8 ± 0.8 ^c	22.7 ± 0.8 ^{NS}	35.8 ± 0.3 ^b	22.3 ± 0.3 ^b	47.5 ± 0.3 ^a	39.0 ± 0.2 ^a	75.2 ± 0.7 ^a	216.7 ± 1.8 ^a	
Nganda (n = 46)	73–192	170	66.8 ± 2.4 ^a	69.6 ± 2.4 ^a	19.9 ± 0.7 ^c	23.5 ± 0.8 ^{NS}	35.9 ± 0.3 ^b	22.8 ± 0.2 ^b	48.9 ± 0.3 ^a	40.4 ± 0.2 ^a	76.3 ± 0.7 ^a	225.3 ± 1.5 ^a	
	7–24	8	8.0 ± 5.0 ^e	27.0 ± 6.0 ^{NS}	16.5 ± 2.5 ^{NS}	12.0 ± 4.0 ^{NS}	34.5 ± 2.5 ^{NS}	19.0 ± 1.0 ^{NS}	42.5 ± 0.5 ^c	34.5 ± 3.5 ^b	70.0 ± 1.0 ^{NS}	186.5 ± 26.5 ^b	
	25–36	11	25.8 ± 4.9 ^e	50.8 ± 7.0 ^{NS}	18.5 ± 2.0 ^{NS}	17.3 ± 2.7 ^{NS}	34.0 ± 0.8 ^{NS}	21.3 ± 0.6 ^{NS}	44.7 ± 1.0 ^c	35.5 ± 0.7 ^b	68.0 ± 4.8 ^{NS}	194.0 ± 4.0 ^b	
EASZ (n = 387)	37–72	14	26.7 ± 4.3 ^e	43.5 ± 5.8 ^{NS}	15.0 ± 1.6 ^{NS}	17.6 ± 2.1 ^{NS}	34.3 ± 0.6 ^{NS}	23.3 ± 0.9 ^{NS}	46.4 ± 0.4 ^c	38.0 ± 0.4 ^b	76.9 ± 1.5 ^{NS}	208.2 ± 1.8 ^b	
	73–192	13	39.2 ± 4.7 ^c	48.9 ± 5.1 ^{NS}	17.6 ± 1.6 ^{NS}	17.9 ± 1.3 ^{NS}	32.7 ± 0.6 ^{NS}	22.0 ± 0.3 ^{NS}	46.3 ± 0.4 ^c	37.7 ± 0.3 ^b	76.2 ± 1.3 ^{NS}	209.1 ± 2.6 ^b	
	7–24	23	8.9 ± 1.4 ^a	22.8 ± 2.4 ^a	11.9 ± 1.0 ^{NS}	11.4 ± 1.2 ^b	31.5 ± 0.5 ^{NS}	19.4 ± 0.6 ^{NS}	41.2 ± 0.6 ^a	34.7 ± 0.7 ^a	64.0 ± 2.3 ^b	180.7 ± 3.5 ^a	
EASZ (n = 387)	25–36	25	12.1 ± 2.5 ^a	26.1 ± 3.7 ^a	11.6 ± 1.5 ^{NS}	12.0 ± 1.6 ^b	32.3 ± 0.6 ^{NS}	19.1 ± 0.2 ^{NS}	42.1 ± 0.5 ^a	34.6 ± 0.4 ^a	65.9 ± 1.6 ^b	193.3 ± 3.3 ^a	
	37–72	110	15.3 ± 0.9 ^a	30.9 ± 1.4 ^a	13.3 ± 0.5 ^{NS}	13.4 ± 0.6 ^b	31.8 ± 0.3 ^{NS}	19.9 ± 0.2 ^{NS}	43.9 ± 0.2 ^a	37.5 ± 0.3 ^a	70.7 ± 0.8 ^b	199.3 ± 1.2 ^a	
	73–192	229	20.6 ± 0.9 ^a	33.2 ± 1.0 ^a	13.7 ± 0.3 ^{NS}	14.6 ± 0.4 ^b	31.4 ± 0.2 ^{NS}	19.8 ± 0.1 ^{NS}	43.9 ± 0.2 ^a	37.2 ± 0.3 ^a	69.3 ± 0.6 ^b	199.0 ± 0.9 ^a	

SE, standard error; HL, horn length; LHT, length between the horn bases; LHB, length between the horn bases; HBC, horn base circumference; FAL, fore arm length; FAC, fore arm circumference; FL, face length; MC, muzzle circumference; TL, tail length; AL, animal length, age is measured in months, linear morphometric traits are measured in centimetres; EASZ, East African shorthorn zebu.

^{a,b,c}Refer to very highly significant ($P \leq 0.000$) differences, highly significant ($P \leq 0.00$) differences and significant ($P \leq 0.05$) differences, respectively. ^{NS}, Not significantly difference. The linear morphometric traits for each breed were compared among the different AEZs in the same column indicated with the same superscript.

The Mahalanobis squared distances were calculated to estimate the levels of linear morphometric trait diversity for female cattle. The Mahalanobis squared distances were significantly different based on pairwise breed comparisons, exhibiting a gradient of low 1.61 (EASZ and Nganda), intermediate 2.09 (Nganda and Ankole) and high 4.15 (EASZ and Ankole) linear morphometric trait diversity as shown in Table 6.

Classification of the study cattle into breed groups using the linear morphometric traits was computed. The correct percentages of breed classification were Nganda (54.4), Ankole (70.1) and EASZ (79.3) as shown in Table 7. The occurrence of misclassification could be indicative of interbreeding between the different breed populations.

Stepwise selection of the five most discriminant linear morphometric traits were identified as HL, FAL, LBT, FL and FAC. These traits may be used to adequately discriminate the three indigenous female cattle breeds. Their levels of discriminating power are shown in Table 8.

Discussion

The present study has revealed that linear morphometric structures of indigenous cattle populations comprising the Ankole, Nganda and EASZ females vary with age, breed types and AEZs. This study utilized female cattle due to the fewer males within sampled herds since the later are kept mainly for breeding purposes. These variations are useful for cattle populations to adapt to different environments, and maybe utilized for livestock breed improvement initiatives and conservation of unique genotypes (Kugonza *et al.*, 2011). The aforementioned structures have been shaped through active selection of unique morphometric traits aimed at promotion of agro-ecological fitness and enrichment of socio-cultural identities among Uganda's cattle keeping communities. Consequently various indigenous cattle populations have evolved in specific AEZs, adopting the names of cattle keeping communities who breed them (Balikowa, 2011). This study reveals a significant upward trend of linear morphometric trait dimensions which may be described as low, intermediate and high for the EASZ, Nganda and Ankole cattle populations, respectively. These findings are in agreement with recent studies by Kugonza *et al.* (2011) who observed that the Ankole cattle have higher body linear measurements compared with the EASZ cattle. Studies in Tanzania (Mwambene *et al.*, 2012) and Kenya (Mwacharo *et al.*, 2006), on the Tanzanian Fipa, Kenyan Kamba and Masai zebu cattle linear morphometric traits revealed that HL, length between the horn tips, HBC measurements are similar to those of EASZ observed in this study although lower than those of Ankole cattle of Uganda. Since the HL and AL are directly correlated to body weights and cattle sizes (Kugonza *et al.*, 2011; Mwambene *et al.*, 2012), then Ankole cattle have evolved

Table 3. Variations of linear morphometric traits of indigenous female cattle breeds sampled from the different AEZs.

Breed	n = 801	AEZ	Morphometric traits (mean ± SE)									
			HL ± SE	LHT ± SE	LHB ± SE	HBC ± SE	FAL ± SE	FAC ± SE	FL ± SE	MC ± SE	TL ± SE	AL ± SE
Ankole (n = 368)	12	NWSG	44.1 ± 6.0 ^a	61.0 ± 5.1 ^a	17.4 ± 1.7 ^a	24.5 ± 2.4 ^a	36.1 ± 0.8 ^a	21.5 ± 0.4 ^a	47.0 ± 1.2 ^a	39.3 ± 0.8 ^a	77.9 ± 2.3 ^b	220.4 ± 5.1 ^a
	47	KP	48.1 ± 4.7 ^a	49.6 ± 3.9 ^a	15.0 ± 0.6 ^a	24.0 ± 1.3 ^a	34.2 ± 0.4 ^a	21.2 ± 0.6 ^a	46.3 ± 0.7 ^a	39.4 ± 0.6 ^a	72.4 ± 1.5 ^b	211.6 ± 3.9 ^a
	28	LVC	28.0 ± 3.3 ^a	40.6 ± 2.9 ^a	17.9 ± 0.9 ^a	17.1 ± 0.5 ^a	32.5 ± 0.6 ^a	21.4 ± 0.4 ^a	44.8 ± 0.4 ^a	37.5 ± 0.4 ^a	73.4 ± 1.7 ^b	201.7 ± 2.7 ^a
	80	WSG	51.0 ± 3.5 ^a	61.3 ± 3.5 ^a	19.1 ± 1.0 ^a	20.9 ± 1.2 ^a	35.7 ± 0.4 ^a	21.8 ± 0.3 ^a	47.1 ± 0.5 ^a	39.4 ± 0.4 ^a	73.4 ± 1.0 ^b	214.6 ± 2.8 ^a
	58	WHR	52.0 ± 3.0 ^a	69.7 ± 3.0 ^a	21.6 ± 1.1 ^a	20.1 ± 1.1 ^a	36.5 ± 0.4 ^a	22.4 ± 0.2 ^a	47.1 ± 0.4 ^a	39.0 ± 0.3 ^a	76.2 ± 1.1 ^b	221.7 ± 2.2 ^a
	109	PR	76.9 ± 2.3 ^a	81.9 ± 2.5 ^a	22.9 ± 1.0 ^a	27.7 ± 1.0 ^a	36.7 ± 0.4 ^a	23.7 ± 0.2 ^a	49.7 ± 0.3 ^a	39.8 ± 0.3 ^a	75.1 ± 0.7 ^b	224.9 ± 2.0 ^a
	34	SWF	80.7 ± 3.9 ^a	85.0 ± 4.8 ^a	27.8 ± 1.9 ^a	21.4 ± 1.5 ^a	36.3 ± 0.4 ^a	23.4 ± 0.2 ^a	49.2 ± 0.6 ^a	39.7 ± 0.4 ^a	80.1 ± 1.8 ^b	223.7 ± 2.5 ^a
Nganda (n = 46)	11	NED	29.1 ± 8.2 ^{NS}	46.3 ± 8.9 ^{NS}	14.8 ± 1.0 ^b	20.5 ± 3.8 ^c	34.2 ± 0.7 ^a	22.5 ± 2.5 ^{NS}	45.3 ± 1.3 ^{NS}	35.1 ± 0.9 ^c	72.8 ± 6.0 ^{NS}	197.3 ± 6.0 ^{NS}
	18	LVC	29.4 ± 2.5 ^{NS}	44.9 ± 2.2 ^{NS}	15.4 ± 0.3 ^b	20.0 ± 1.0 ^c	31.7 ± 0.5 ^a	21.6 ± 0.3 ^{NS}	46.1 ± 0.3 ^{NS}	37.8 ± 0.3 ^c	76.8 ± 1.1 ^{NS}	204.7 ± 1.2 ^{NS}
	17	PR	33.8 ± 5.9 ^{NS}	47.9 ± 7.8 ^{NS}	18.2 ± 2.1 ^b	14.4 ± 2.0 ^c	35.0 ± 0.6 ^a	23.1 ± 0.6 ^{NS}	46.2 ± 0.5 ^{NS}	37.8 ± 0.5 ^c	75.5 ± 1.9 ^{NS}	210.5 ± 3.4 ^{NS}
EASZ (n = 387)	67	KP	23.3 ± 1.8 ^a	33.0 ± 1.8 ^b	13.7 ± 0.6 ^{NS}	15.2 ± 0.7 ^a	31.8 ± 0.4 ^c	20.4 ± 0.2 ^c	45.4 ± 0.4 ^b	38.4 ± 0.4 ^a	77.1 ± 1.0 ^a	204.1 ± 2.2 ^c
	12	LVC	20.0 ± 3.0 ^a	40.1 ± 4.0 ^b	20.0 ± 1.0 ^{NS}	14.5 ± 0.5 ^a	34.0 ± 1.0 ^c	21.5 ± 1.5 ^c	45.5 ± 4.5 ^a	41.5 ± 4.5 ^a	72.5 ± 2.5 ^a	210 ± 1.0 ^c
	45	NED	14.6 ± 1.6 ^a	26.6 ± 2.3 ^b	12.0 ± 1.0 ^{NS}	11.7 ± 1.0 ^a	31.8 ± 0.3 ^c	19.7 ± 0.4 ^c	43.8 ± 0.3 ^a	35.9 ± 0.3 ^a	66.5 ± 1.6 ^a	198.5 ± 1.3 ^c
	91	NESG	16.1 ± 1.0 ^a	29.3 ± 1.6 ^b	12.8 0.6 ^{NS}	13.4 ± 0.6 ^a	31.1 ± 0.3 ^c	19.2 ± 0.2 ^c	43.6 ± 0.3 ^a	36.8 ± 0.3 ^a	69.6 ± 0.8 ^a	195.1 ± 1.5 ^c
	107	NWSG	17.0 ± 0.9 ^a	32.5 ± 1.3 ^b	13.8 ± 0.4 ^{NS}	14.1 ± 0.5 ^a	31.4 ± 0.2 ^c	19.2 ± 0.2 ^c	42.8 ± 0.2 ^a	35.4 ± 0.4 ^a	66.4 ± 0.8 ^a	195.3 ± 1.2 ^c
	16	PS	13.5 ± 1.6 ^a	33.1 ± 2.5 ^b	15.0 ± 0.5 ^{NS}	14.1 ± 0.6 ^a	30.8 ± 0.3 ^c	19.5 ± 0.3 ^c	41.9 ± 0.4 ^a	35.0 ± 0.5 ^a	63.0 ± 1.0 ^a	193.8 ± 2.5 ^c
	29	PR	11.6 ± 1.3 ^a	29.8 ± 2.9 ^b	12.2 ± 1.1 ^{NS}	11.5 ± 1.1 ^a	30.6 ± 0.7 ^c	22.0 ± 0.5 ^c	44.1 ± 0.4 ^b	41.7 ± 0.8 ^a	66.6 ± 1.3 ^a	198.6 ± 2.4 ^c
	20	WSG	31.6 ± 5.4 ^a	41.9 ± 5.1 ^b	13.8 ± 0.9 ^{NS}	18.4 ± 2.0 ^a	33.7 ± 0.9 ^c	20.1 ± 0.4 ^c	44.2 ± 0.9 ^a	37.9 ± 0.8 ^a	70.8 ± 2.5 ^a	199.2 ± 5.1 ^c

AEZ, Agro-ecological zone; SE, standard error; HL, horn length; LHT, length between tips; LHB, length between the horn bases; HBC, horn base circumference; FAL, fore arm length; FAC, fore arm circumference; FL, face length; MC, muzzle circumference; TL, tail length; AL, animal length; EASZ, East African shorthorn zebu; NED, northeastern drylands; NESG, northeastern savannah grasslands; NWSG, northwestern savannah grasslands; KP, Kyoga Plains; LVC, Lake Victoria Crescent; WSG, western savannah grasslands; WHR, western Highland ranges; PR, pastoral rangelands, southwestern Farmlands; PS, para savannahs.

^{a,b,c}Refer to very highly significant ($P \leq 0.000$) differences, highly significant ($P \leq 0.00$) differences and significant ($P \leq 0.05$) differences, respectively. The linear morphometric traits for each breed were compared among the different AEZs in the same column indicated with the same superscript.

Table 4. Linear regression parameter estimates for prediction of the linear morphometric traits of female cattle based on the breeds and age groups.

	Morphometric trait (cm)										
	HL	LHT	LHB	HBC	FAL	FAC	FL	MC	TL	AL	
<i>Breed group</i>											
Ankole	-26.9 ± 3.5***	-21.0 ± 3.6***	-3.9 ± 1.2**	-5.5 ± 1.3***	-2.4 ± 0.5***	-0.1 ± 0.4 ^{NS}	-1.7 ± 0.5*	-1.9 ± 0.5***	0.5 ± 1.3 ^{NS}	-12.1 ± 2.7***	
Nganda	-42.4 ± 1.6***	-36.6 ± 1.7***	-7.3 ± 0.6***	-9.3 ± 0.6***	-4.2 ± 0.2***	-2.8 ± 0.2***	-4.2 ± 0.2***	-2.5 ± 0.2***	-5.9 ± 0.6***	-21.3 ± 1.2***	
<i>Age (months) group</i>											
7-24											
25-36	4.5 ± 4.4 ^{NS}	3.4 ± 4.6 ^{NS}	2.2 ± 1.5 ^{NS}	0.06 ± 1.6 ^{NS}	1.4 ± 0.7*	0.5 ± 0.4 ^{NS}	1.7 ± 0.6**	0.8 ± 0.7 ^{NS}	1.1 ± 1.8 ^{NS}	10.4 ± 3.5***	
37-72	12.7 ± 3.7***	10.6 ± 3.9***	2.5 ± 1.3*	0.9 ± 1.4 ^{NS}	0.9 ± 0.6 ^{NS}	0.8 ± 0.4 ^{NS}	3.4 ± 0.5***	3.1 ± 0.6***	6.5 ± 1.4***	20.8 ± 2.9***	
73-192	20.4 ± 3.6***	11.9 ± 3.8**	1.9 ± 1.2 ^{NS}	1.8 ± 1.4 ^{NS}	0.8 ± 0.5 ^{NS}	0.9 ± 0.4*	4.1 ± 0.5***	3.7 ± 0.6***	6.3 ± 1.5***	24.7 ± 2.9***	
Constant	44.3 ± 3.6***	57.8 ± 3.8***	18.7 ± 1.2***	21.9 ± 1.3***	34.9 ± 0.5***	21.7 ± 0.4***	44.3 ± 0.5***	36.3 ± 0.6***	69.3 ± 1.4***	197.8 ± 3.8***	
Adjusted R ²	0.5	0.36	0.18	0.21	0.27	0.21	0.32	0.16	0.13	0.31	

EASZ, East African shorthorn zebu; SE, standard error; HL, horn length; LHT, length between the horn tips; LHB, length between the horn bases; HBC, horn base circumference; FAL, face length; FAC, face length; FL, face length; MC, muzzle circumference; TL, tail length; AL, animal length.

^{NS}, Not significant ($P > 0.05$); ***, very highly significant ($P < 0.001$); **, highly significant ($P < 0.01$); *, Significant ($P \leq 0.05$).

comparatively superior linear morphometric traits and body sizes compared with the EASZ.

The Mahalanobis squared distances computed among the three female cattle breeds were significantly different corresponding to high linear morphometric diversity among the study indigenous cattle breed types. This agrees with Ndumu *et al.* (2008b) who observed significant differences of morphometric distances between different clusters of Ankole cattle. The linear morphometric diversity was observed to be low between the EASZ and Nganda, intermediate between the Nganda and Ankole and high among the Ankole and the EASZ breeds. Recently, Bett *et al.* (2013) have reported that the Nganda group is a hybrid of the Ankole and EASZ, although more closely associated with the later. This explains the occurrence of low morphometric distances between Nganda and EASZ, and intermediate between the Nganda and Ankole. Similarly, the high morphometric distance between the Ankole and EASZ is strongly suggestive of high trait diversity between the two populations. These distances correspond to traditional farmers' dissimilarities of selective breeding criteria for desirable traits to enhance adaptation to contrasting AEZs.

The AEZ attributes support indigenous cattle through provision of natural pasture feeds, water resources and suitable ambient temperatures. Lately, Balikowa (2011) has noted that the Ankole cattle are established in the southern and Western Uganda. These regions are characterized by comparatively higher altitudes, lower ambient temperature ranges and abundant rainfall patterns (>2 100 mm). These conditions favour good pasture rangelands, resulting into more feed resource availability. The exhibition of higher linear morphometric traits among the Ankole of the SWF, PR and WHR AEZs could be partly due to the availability of comparatively higher natural pasture and water resources compared with the northeastern drylands and northwestern savannah grasslands. Indeed, Mwambene *et al.* (2012) have recently noted that variations in availability of feed resources and farmers' breeding practices plus natural breeding barriers such as detachment between different locations largely account for morphometric trait differences. Similarly, Ankole cattle keepers have memorized selective breeding criteria based on customary knowledge to enhance higher productivity, socio-cultural identity and beauty. These criteria favour larger body sizes, tall frames and large white curved horns for the cows. Similar selection criteria for bulls have been described (Ndumu *et al.*, 2008a; Kugonza *et al.* 2011, 2012), which largely accounts for socio-cultural identity of Ankole cattle populations.

The EASZ cattle exhibited comparatively lower linear morphometric trait dimensions which occurred in the NED, PS, NESG and NWSG AEZs. The northeastern, northern and northwestern regions are characterized by lower altitudes, higher ambient temperatures and lower

Table 5. Pairwise correlation coefficients and their significance levels among the linear morphometric traits.

Traits	HL	LHT	LHB	HBC	FAL	FAC	FL	MC	TL	AL
(a) Female Ankole cattle ($n = 368$)										
HL	1									
LHT	0.60***	1								
LHB	0.44***	0.38***	1							
HBC	0.37***	-0.37***	0.36***	1						
FAL	0.42***	0.32***	0.28***	0.15**	1					
FAC	0.47***	0.39***	0.24***	0.19***	0.35***	1				
FL	0.66***	0.45***	0.22***	0.32***	0.45***	0.45***	1			
MC	0.50***	0.30***	0.05 ^{NS}	0.19***	0.31***	0.40***	0.65***	1		
TL	0.19***	0.25 ^{NS}	-0.04***	0.18***	0.18***	0.17***	0.30***	0.30***	1	
AL	0.56***	0.38***	0.19***	0.19***	0.37***	0.42***	0.57***	0.57***	0.27***	1
(b) Female Nganda cattle ($n = 46$)										
HL	1									
LHT	0.74***	1								
LHB	0.70***	0.66***	1							
HBC	0.53***	0.60***	0.28*	1						
FAL	0.07 ^{NS}	0.00 ^{NS}	0.10 ^{NS}	-0.04 ^{NS}	1					
FAC	0.12 ^{NS}	-0.09 ^{NS}	-0.06 ^{NS}	-0.03 ^{NS}	0.32*	1				
FL	0.49***	0.40**	0.22 ^{NS}	0.33*	0.11 ^{NS}	0.25 ^{NS}	1			
MC	0.20 ^{NS}	0.05 ^{NS}	-0.18 ^{NS}	0.07 ^{NS}	0.25 ^{NS}	0.23 ^{NS}	0.45**	1		
TL	0.12 ^{NS}	0.06 ^{NS}	-0.03 ^{NS}	0.22 ^{NS}	0.19 ^{NS}	0.37*	0.23 ^{NS}	0.44**	1	
AL	0.04 ^{NS}	-0.10 ^{NS}	-0.15 ^{NS}	-0.04 ^{NS}	0.31**	0.45**	0.29*	0.55***	0.55***	1
(b) Female EASZ cattle ($n = 387$)										
HL	1									
LHT	0.66***	1								
LHB	0.55***	0.73***	1							
HBC	0.73***	0.83***	0.78***	1						
FAL	0.19***	0.09 ^{NS}	0.11*	0.11*	1					
FAC	0.14**	0.07 ^{NS}	0.05 ^{NS}	0.09 ^{NS}	0.11*	1				
FL	0.43***	0.26***	0.17***	0.27***	0.22***	0.42***	1			
MC	0.20***	0.15**	0.02 ^{NS}	0.08 ^{NS}	0.02 ^{NS}	0.32***	0.46***	1		
TL	0.33***	0.23***	0.16**	0.27***	0.14**	0.31***	0.51***	0.40***	1	
AL	0.46***	0.32***	0.23***	0.34***	0.19***	0.38***	0.67***	0.37***	0.42***	1

EASZ, East African shorthorn zebu; HL, horn length; LHT, length between the horn tips; LHB, length between the horn bases; HBC, horn base circumference; FAL, fore arm length; FAC, fore arm circumference; FL, face length; MC, muzzle circumference; TL, tail length; AL, animal length. ^{NS}, Not significant ($P > 0.05$); ***, very highly significant ($P < 0.001$); **, highly significant ($P < 0.01$); *, significant ($P \leq 0.05$).

rainfall patterns (<500 mm) which consequently lower the availability of pasture and water resources (Balikowa, 2011). Consequently, indigenous livestock farmers' selection criteria tend to favour cattle's ability to survive under lower feed and water availability (FAO, 2007; Nalule, 2010) which in turn influences lower body sizes of EASZ cattle breed types. Selection of smaller body measurements have enabled the comparatively smaller EASZ cattle to thrive under the less privileged climatic, feed and water resource conditions (Loquang and Köhler-Rollefson, 2005; FAO, 2009).

Table 6. Mahalanobis squared distances between the three female cattle groups.

Breed		Ankole ($n = 368$)	Nganda ($n = 46$)	EASZ ($n = 387$)
Ankole	Mahalanobis squared distance	0	2.09***	4.15***
Nganda	Mahalanobis squared distance		0	1.61***

EASZ, East African shorthorn zebu.
Very highly significant at $P < 0.000$.

The majority of pairwise correlation coefficients between the linear morphometric measurements were positive and highly significant. This enables accurate estimation of unavailable but correlated traits. More so in case of inability to directly measure the trait at a point in time necessitating longitudinal studies to be accurately estimated such as production traits as previously observed by Kugonza *et al.* (2011), among the Ankole cattle. Most significant pairwise correlations were evident among the Ankole, followed by the EASZ and least among the Nganda cattle. The cause for the differences in the level of correlation

Table 7. Percentage classifications of indigenous cattle into their breed groups using the linear morphometric traits.

Breeds	Female cattle ($n = 801$)		
	Ankole ($n = 368$)	Nganda ($n = 46$)	EASZ ($n = 387$)
Ankole	70.11	13.32	16.58
Nganda	19.57	54.35	26.09
EASZ	4.13	16.54	79.33

EASZ, East African shorthorn zebu.

Table 8. Stepwise selection summary of the five most discriminant linear morphometric traits.

Step	Trait entered	R^2	F value	P value
1	HL	0.389	587.76	0.000
2	FAL	0.040	64.14	0.000
3	LBT	0.016	26.24	0.000
4	FL	0.004	6.21	0.013
5	FAC	0.005	7.56	0.006

HL, horn length; FAL, fore arm length; LBT, length between the horn tips; FL, face length; FAC, fore arm circumference.

among the linear morphometric traits between specific cattle breeds requires more investigations.

The study of linear morphometric traits were used to classify the female cattle into their breed groups of Ankole, EASZ and Nganda resulting into variable grades of accuracy. The occurrence of inaccurate classification is largely due to interbreeding between populations as preferred by traditional farmers, for example crossbreeding the Ankole and EASZ has resulted into composite cattle breeds such as the Nganda. While interbreeding between the different EASZ has given rise to Nkedi and Nsoga cattle populations (Bett *et al.*, 2013), crossbreeding is common in AEZs harbouring more than one indigenous breed types and where exotic genotypes such as Friesians are being popularized for increased productivity, such as among smallholder dairy farmers in central Uganda. Linear morphometric traits within the same breed populations sampled from different AEZs exhibited significant differences which could be

**Figure 3.** A herd of the Ankole cattle from pastoral rangelands of Southwestern Uganda.

associated with morphological signatures of selection between the zones. The Ankole, EASZ and Nganda cattle exhibited high, moderate and low within breed significant differences of the study morphometric traits, respectively. This further supports previous observations in which traditional farmers' diverse selective breeding criteria within indigenous cattle populations for agro-ecological fitness resulting into evolution of unique cattle morphometric populations (FAO, 2009). This is also comparable with Ndumu *et al.* (2008b)'s findings that identified three sub-populations using micro-satellite markers and morphological analysis within Southwestern Uganda.

Conclusions

This study has provided insight on the extent to which traditional farmers' selective breeding practices enhance identity and agro-ecological fitness resulting into creation of unique indigenous cattle morphometric populations. Secondly, the study has revealed that indigenous cattle linear morphometric variation is structured geographically with higher linear morphometric trait dimensions being exhibited in the southern, southwestern and western regions of Uganda. Although lower trait dimensions occur towards the northern, northwestern and northeastern regions which further corresponds to lower availability of natural feed and water resources. The high morphometric diversity among indigenous cattle population can be a basis for improvement and conservation with farmers' preferences and adaptation to the different AEZs. Appropriate management practices, including feeding, disease control and selective breeding will further enhance sustainable production more so in areas where no other type of agricultural investment is possible.

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**Figure 2.** (a) A herd of the East African shorthorn zebu (EASZ) cattle from northeastern drylands (NED) of Uganda. (b) A herd of the East African shorthorn zebu (EASZ) cattle from northwestern savannah grasslands (NWSG) of Uganda.

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Statement of interest

The authors declare no conflict of interest.

Ethical clearance statement

This study was guided by the guidelines stated in the Guide for the Care and Use of Agricultural Animals in Research and Teaching (FASS, 2010).

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