

REGULAR ARTICLE

Morphological diversities and eco-geographical structuring of Ethiopian camel (*Camelus dromedarius*) populations

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Abstract

The objectives of this study were to identify and characterize indigenous camel ecotypes and to assess phenotypic diversity and relationship of camel populations in Ethiopia. A total of 494 heads of camels were investigated for phenotypic characterization. The study involved Jijiga, Liben, Gelleb, Hoor and Shinille from Somali as well as Amibara and Mille camel populations from Afar national regional states, which are the major camel rearing areas. The results showed that average barrel and heart girths of Liben camel population were significantly ($p < 0.05$) larger than the remaining camel populations. Gelleb camels were significantly ($p < 0.05$) superior for morphological variables particularly height at shoulder, chest depth, chest width and hip width to other camel populations examined. Females of Amibara camel population recorded significantly ($p < 0.05$) lower values for traits mentioned above as compared to other camel populations. The greatest morphological divergence was observed between Mille and Shinille followed by the difference between Amibara and Shinille camel populations. The least morphological divergence was detected between Hoor and Gelleb followed by that between Amibara and Mille camels in aggregate gender. Quantitative and qualitative study indicated that Jijiga and Hoor camel populations are milk type whereas Liben and Gelleb camel populations are meat type. The principal component analysis showed that body height traits and body height together with body shape traits explained most of the shared variability in female and male camel populations, respectively. The canonical analysis identified two canonical variables to be significant ($p < 0.0001$) and sufficient to classify all camels studied. Combined differences among all morphological variables categorized these seven Ethiopian camel populations into five major camel groups. Therefore the findings from this study can be used for the description of body conformation, characterization, improvement and conservation of various camel populations in the country.

Key words: Body measurement, Camel population, Diversity, Morphology

Introduction

Camels are the most capable animals in utilizing marginal areas because they can survive under harsh environmental conditions. Many pastoral groups and communities in diverse eco-zones throughout the world are depending on camels for their livelihoods. The world camel population is estimated to be around 25 million, of which 11 million are present in arid and semi-arid

regions, particularly in the arid lowlands of East Africa (FAOSTAT, 2011). Even though the exact number is not known, approximately 2,400,000 camels are reported to prevail in Ethiopia (FAOSTAT, 2011), of which the Somali and Afar regional states keep around 92% of the total camel population (LDMPS, 2006).

Utilization of camel in Ethiopia is basically traditional and no camel ecotype is specialized for milk, meat, draft or racing purpose except for the pastoralists' traditional classification of camel types in Somali regional state. In this region, pastoralists classify camel population based on some phenotypic descriptors. According to their perception, some of the camel ecotypes are taller while others have a wider hip. They also distinguish different camel ecotypes for milk, meat

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and dual purposes. Moreover, they have the opinion that some of the camel ecotypes are more adaptive to harsh environment than others (Ahmed, 2002). According to FAO (2011), the traditional classification should be used as a basis for phenotypic and genetic characterization studies.

However, study on camel production system, phenotypic and genetic characterization is scanty (Yohannes et al., 2007) and there is a serious lack of information on camel genetic diversity in East Africa (Gifford-Gonzalez and Hanotte, 2011). This hindered the design of appropriate strategy for utilization of existing potential of camel genetic resources and establishment of breeding programs. Given the current importance of camels in contributing to the livelihoods of large human population in marginal areas, and the role it plays towards resilience to present climate change, it is imperative to identify and differentiate the phenotypic characteristics of camel populations in Ethiopia based on FAO guidelines. Therefore the present study was undertaken with the objectives to identify and characterize indigenous camel ecotypes of south, east and northeastern Ethiopia and to describe the relationship of these camel populations.

Materials and Methods

Study area

The study involved two major camel rearing geographical locations viz. Somali and Afar national regional states (Figure 1). The two regional states accounted for about 92% of the camel population in Ethiopia and were purposively selected for the study. The specific study sites from Somali national regional state included three rural localities (RLs) from Jijiga District (representing Jijiga camel population), four RLs from Gode District (two RLs each for Hoor and Gelleb camel populations), four RLs from Moyale District (Liben camel population) and two RLs from Shinille District (Shinille camel population). The sampling area from Afar national regional state involved two RLs from Mille District (Mille camel population), and two and one RLs from Amibara and Dulesa Districts, respectively (Amibara camel population). The study sites were purposively selected based on traditional classification of camel populations while households were selected randomly. Exploratory approach (undertaken in situations in which no reliable background information on the existence of recognized breeds in the study area was available) was used in the absence of traditional classification.

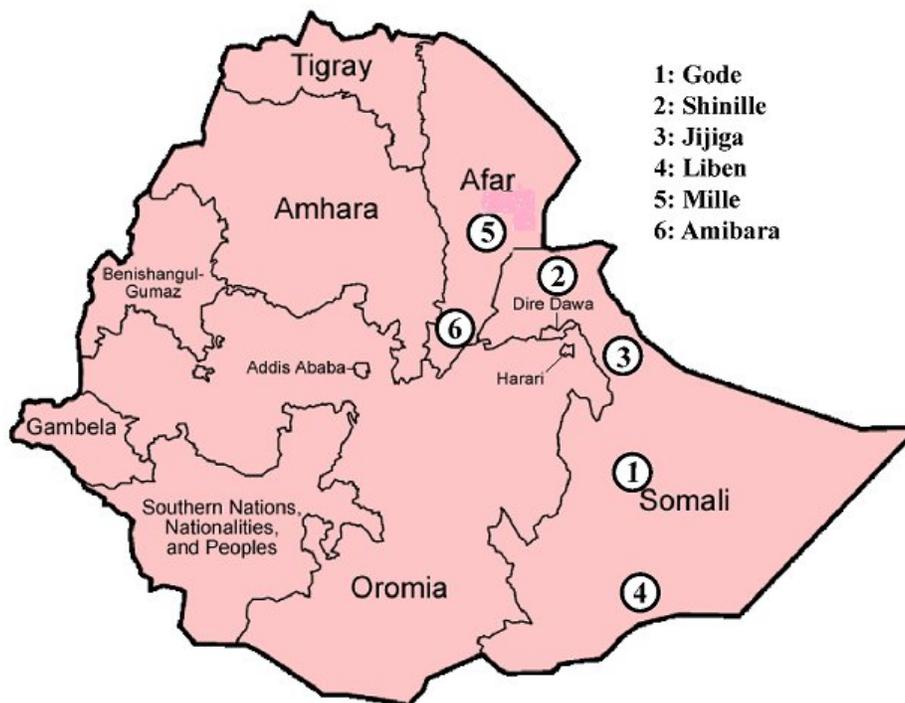


Figure 1. Map of study areas in Afar and Somali regional states, Ethiopia.

Methods for data collection and description of morphological variables

A rapid rural appraisal technique was applied to collect data. Structured questionnaires were used to gather information from pastoral households so that to generate relevant information on husbandry practices of camels, historical perspectives and people's perception of camel rearing, and traditional ways of classifying and describing the differences among and within camel populations as well as of understanding breed characteristics in terms of milk yield, resistance to drought and related environmental hazards, selection criteria, and qualitative descriptions of camels such as body color, hair length and distribution, hump, ear size, ear orientation, tail length, and udder size. Moreover, relevant information was generated and physical data was obtained through informal group discussion held with key informants (elders, community leaders and development agents) at all study sites and at various levels. Information collected during group discussion was supported by personal observation during a transect walk where critical environmental observation was done. Camels above eight years of age were used for linear measurement. Age was determined based on dentition and also information obtained from the owners.

Data collection formats for discrete/qualitative, quantitative, herd level data, and origin and development of camels were adapted from FAO guidelines on phenotypic characterization (FAO, 2011). In this study, a total of 103 male and 391 female mature (full mouth) and unrelated camels were randomly selected from the identified populations (Table 1). The populations were identified during the exploratory assessment in reference to the traditionally recognized types, the geographical differences among the populations, and the ethnic nomenclature. A total of 18 different body measurements were recorded for each of the sampled individuals within the population. Measurements were taken using a measuring tape while the animals were standing on level ground. The types and anatomical positions of different linear measurements taken are indicated in Table 2 and Figure 2. Body weight estimation was done using Barymetric weight estimation formula of Yagil (1994):

$$Y = SH \times TG \times BG \times 50$$

Where, Y = The weight in kg.

SH = The height at shoulder in meters.

TG = The chest girth behind the chest pad in meters.

BG = The barrel girth over the highest part of the hump in meters.

Table 1. Number of males, females and total number of camels sampled per population.

Populations	Females	Males	Total	Percentage	Cumulative percentage
Amibara	57	14	71	14.37	14.37
Gelleb	57	14	71	14.37	28.74
Hoor	56	14	70	14.17	42.91
Jijiga	58	15	73	14.77	57.68
Liben	53	15	68	13.77	71.46
Mille	58	14	72	14.57	86.03
Shinille	52	17	69	13.97	100.00
Total	391	103	394		

Table 2. Definition of morphological variables measured on Ethiopian camels.

Morphological variables ^a
1. Heart or Chest girth (cm): the circumference of the body immediately behind the shoulder blades in a vertical plane, perpendicular to the long axis of the body as quantified using a measuring tape (F).
2. Height at shoulder/wither (cm): the height (vertical) from the bottom of the front foot to the highest point of the withers measured using a measuring stick (C-G).
3. Barrel girth (cm): the measurement of the distance around the abdomen over the highest part of the hump measured by a measuring tape (E).
4. Body length (cm): the horizontal distance from the point of shoulder to the pin bone measured using a measuring stick (A-D).
5. Depth of chest (cm): distance from wither to sternum measured using a measuring tape (G-H).

Table 2. Contd..

6. Width of chest (cm): distance from left to the right upper arm measured using a measuring tape (M-N).
7. Width of hip (cm): distance from the left to the right point of hip measured using a measuring tape (K-L).
8. Length of forelimb (cm): distance from the surface of the ground level to front of sternum measured using a measuring stick (C-D).
9. Length of hind limb (cm): distance from the bottom of the leg to the pin bone of hip measured using a measuring stick (A-B).
10. Tail length: distance from the tail base to the tip of tail measured by a measuring tape (I-J).
11. Hind leg hoof circumference: circumference of hind leg hoof around the wider part measured using a measuring tape (V).
12. Foreleg hoof circumference: circumference of foreleg hoof around the wider part measured using a measuring tape (U).
13. Hump circumference: the perimeter of the hump from a point at the anterior end of the hump to a point at its posterior end measured using a measuring tape (Z1).
14. Hump length: length from the bottom to the tip of the hump measured using a measuring tape (Y-Z).
15. Neck length: distance from the lower part of mandible to the sternum measured using a measuring tape (O-P).
16. Face length: distance from the midpoint of the two ears to the mouth measured using a measuring tape (Q-R).
17. Ear length: length of the external ear from its root on the base to the tip measured using a measuring tape (X-W).
18. Distance between eyes: distance between the two eyes measured using a measuring tape (S-T).

^aLetters in parenthesis indicate positions of measurements as illustrated in Figure 2.

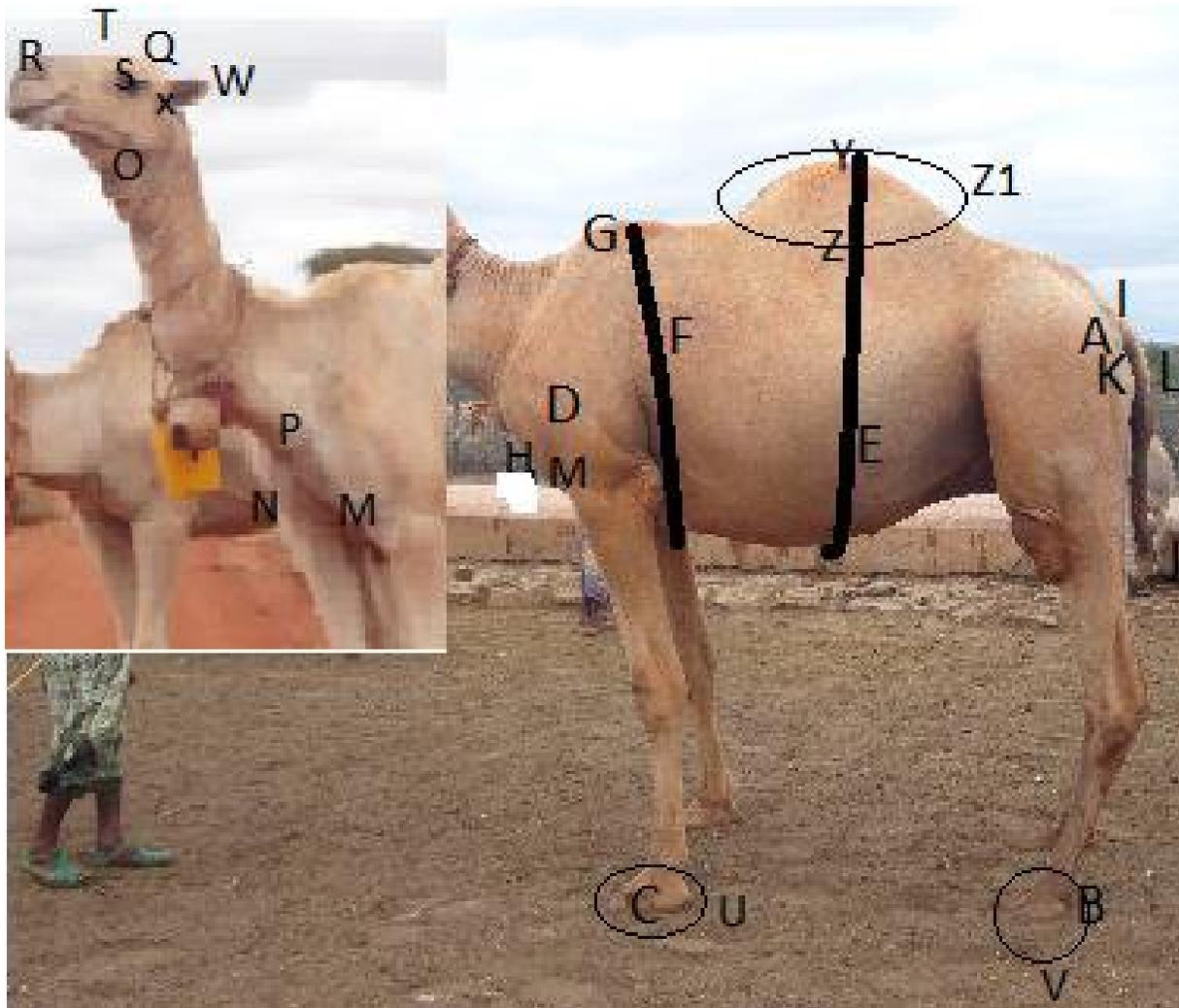


Figure 2. Positions of the various morphological variables measured on a camel.

Data analysis

Data were analyzed using the GLM procedure of SAS (2008). Descriptive statistics, univariate and multivariate analyses were employed. Cluster analysis was undertaken to identify groups of individuals that are similar to each other but different from individuals in other groups. Discriminant analysis was employed to define the relationship between independent and dependent variables on data sets for which pre-specified and well defined groups already exist.

Principal component analysis (PCA) was carried out for the two genders separately to determine different variables or parameters for differentiation of camel populations into different groups that were mutually exclusive, and to summarize the variables into few meaningful ones that accounted for most of the variations in the population. Cross validation for proper classification of different camel groups in the original population and tolerance evaluation were undertaken for each sex separately and for aggregate gender. In addition, Eigen values greater than one was described in the principal component analysis. After tolerance evaluation, some variables that did not reveal significant difference among male camel populations were removed.

Canonical discriminant function analysis was also performed to find out linear combination of quantitative variables that gave maximal separations between populations. The scored canonical variables were used to plot pairs of canonical variables to aid visual interpretation of group differences. In order to know the relationship of hump length and barrel girth with other variables, both traits were measured separately. To avoid redundancy, hump length was removed from all analyses except for mean comparison and PCA.

A stepwise procedure was used to determine the relationship among different populations. In the stepwise procedure, discriminant analysis with forward selection procedure was carried out to find out variables that best showed differences among populations and to identify important discriminating variables. Some variables that had below 0.1 tolerance values were not described but variables with wilks' lambda values close to zero or one were described. Squared Mahalanobis distance was computed between populations as:

$$D^2_{(ij)} = (\bar{X}_i - \bar{X}_j)' \text{COV}^{-1} (\bar{X}_i - \bar{X}_j)$$

Where D^2_{ij} is the distance between populations i and j , COV^{-1} is the inverse of the covariance matrix of measured variables, y and \bar{x}_i and \bar{x}_j are the means of variable y in i^{th} and j^{th} populations, respectively. Squared Mahalanobis distance matrix was used via agglomerative hierarchical cluster procedure to build a dendrogram using unweighted pair group method with arithmetic mean (UPGMA) employing tree procedure in SAS (2008). Thus distance between populations based on Mahalanobis distance procedure (Mahalanobis, 1936) was used.

Results

Breed means and mean comparisons

Mean values of the 18 morphological variables and body weight of the seven Ethiopian camel populations are presented for male, female and aggregate gender in Tables 3, 4 and 5, respectively. Pair wise mean comparison showed significant differences for most of the morphological variables among male camel populations. Height at shoulder (HS), body length (BL), heart girth (HG), barrel girth (BG) and body weight (BW) were significantly ($p < 0.05$) higher for Liben male camels than other male camel populations. Hoor and Gelleb male camels had significantly ($p < 0.05$) higher chest depth (CD), chest width (CW) and hip width (HW) than other male camel populations. But Gelleb and Hoor male camel populations recorded a significantly ($p < 0.05$) lower HG than males from other camel populations. Males of Mille and Liben camel populations were superior ($p < 0.05$) in length of hind (LHL) and forelegs (LFL) to other male camel populations studied. Shinille male camels were significantly ($p < 0.05$) superior in hind (HLHC) and forelegs (FLHC) hoof circumferences to males of other camel populations. Males of Gelleb and Liben camel populations were significantly ($p < 0.05$) superior in hump circumference (HC) to males of other camel populations studied (Table 3).

Table 3. Mean and pair wise comparison of morphological variables (cm) with their standard errors in each camel population: Male.

Traits ^b	Camel populations						
	Jijiga	Hoor	Gelleb	Amibara	Mille	Liben	Shinille
No.	15	14	14	14	14	15	17
HG	198.20(3.33) ^{bcd}	194.00(1.09) ^d	196.85(0.52) ^{cd}	200.71(1.12) ^{bc}	202.57(1.36) ^b	219.86(1.58) ^a	185.52(0.66) ^e
BG	240.33(3.78) ^b	236.35(0.99) ^{bc}	238.21(0.59) ^{bc}	233.14(0.99) ^{cd}	237.07(0.98) ^{bc}	265.26(1.83) ^a	230.64(1.15) ^d
HS	184.26(2.74) ^c	201.64(1.13) ^a	205.78(0.58) ^a	194.71(0.69) ^b	196.71(0.81) ^b	205.13(2.60) ^a	184.52(1.23) ^c
BW	443.13(20.57) ^c	462.64(6.50) ^{bc}	482.61(3.57) ^b	455.83(5.54) ^{bc}	477.08(7.49) ^b	599.58(14.23) ^a	407.59(3.76) ^d
BL	134.20(2.32) ^b	149.71(0.39) ^a	150.07(0.47) ^a	129.42(1.34) ^c	130.14(1.13) ^c	149.26(2.67) ^a	146.70(0.83) ^a
CD	67.26(2.93) ^b	82.00(0.65) ^a	80.57(0.40) ^a	56.14(1.74) ^d	55.35(0.78) ^d	64.26(1.46) ^{bc}	61.05(0.77) ^c
CW	40.26(1.92) ^c	52.28(1.18) ^a	54.14(0.55) ^a	39.85(0.83) ^c	48.07(0.65) ^b	52.66(2.08) ^a	47.58(0.35) ^b
HW	41.73(1.16) ^c	46.50(0.85) ^a	44.64(0.57) ^{ab}	36.64(0.42) ^d	42.71(0.62) ^{bc}	44.40(0.82) ^{ab}	42.47(0.44) ^{bc}
LHL	155.20(1.48) ^d	161.35(0.74) ^c	162.71(0.56) ^{bc}	164.50(1.44) ^{bc}	165.92(2.05) ^{ab}	169.33(1.86) ^a	147.11(0.74) ^e
LFL	147.06(1.08) ^d	155.64(0.45) ^c	156.35(0.67) ^{bc}	154.35(0.89) ^c	158.92(1.31) ^{ab}	160.20(1.75) ^a	142.11(0.67) ^e
TL	63.13(3.06) ^{bc}	69.00(0.55) ^a	70.21(0.48) ^a	61.21(0.53) ^c	67.07(0.67) ^{ab}	59.80(2.41) ^c	54.88(0.42) ^d
FLHC	66.26(1.96) ^d	75.57(0.85) ^b	71.85(0.43) ^c	66.07(0.67) ^d	63.42(0.76) ^d	76.73(1.03) ^b	95.64(1.10) ^a
HLHC	60.00(1.14) ^d	70.71(0.80) ^c	72.00(1.52) ^c	58.42(0.40) ^d	57.78(0.57) ^d	78.66(2.59) ^b	87.82(0.90) ^a
HC	108.40(8.05) ^c	137.28(0.78) ^b	141.42(0.73) ^{ab}	88.35(1.92) ^d	95.35(0.76) ^d	153.06(6.31) ^a	91.41(3.01) ^d
HL	31.66(2.04) ^b	33.85(0.65) ^b	33.57(0.38) ^b	21.71(0.26) ^c	22.57(0.30) ^c	37.66(1.55) ^a	22.11(0.34) ^c
NL	93.20(3.33) ^d	120.00(0.93) ^a	122.57(0.57) ^a	101.85(1.37) ^c	101.92(0.72) ^c	108.20(3.70) ^b	99.52(0.64) ^c
FCL	51.33(0.31) ^c	58.28(0.80) ^b	60.92(0.70) ^a	52.71(0.42) ^c	53.07(0.48) ^c	57.80(0.92) ^b	45.17(0.29) ^d
EL	11.80(0.14) ^b	11.57(0.13) ^b	12.00(0.14) ^{ab}	12.07(0.16) ^{ab}	12.00(0.18) ^{ab}	12.06(0.26) ^{ab}	12.47(0.12) ^a
DES	24.40(0.48) ^b	22.28(0.22) ^c	24.50(0.17) ^b	21.28(0.33) ^d	22.14(0.25) ^{cd}	24.26(0.35) ^b	25.47(0.19) ^a

^bHG = Heart girth, BG = Barrel girth, HS = Height at shoulder/wither, BW = Body weight, BL = Body length, CD = Chest depth, CW = Chest width, HW = Hip width, LHL = Length of hind leg, LFL = Length of foreleg, TL = Tail length, FLHC = Foreleg hoof circumference, HLHC = Hind leg hoof circumference, HC = Hump circumference, HL = Hump length, NL = Neck length, FCL = Face length, EL = Ear length, DE = Distance between eyes. Figures in parentheses = s.e. Different superscripts labeled for values in the same row indicate their statistical significances at p<0.05. The same abbreviations and rules are also applied to all relevant tables and figures.

Table 4. Mean and pair wise comparison of morphological variables (cm) with their standard errors in each camel population: Female.

Traits	Camel populations						
	Jijiga	Hoor	Gelleb	Amibara	Mille	Liben	Shinille
No.	58	56	57	57	58	53	52
HG	198.89(1.68) ^c	210.35(0.62) ^b	214.67(1.33) ^a	181.89(0.75) ^e	185.25(0.45) ^d	209.64(1.45) ^b	185.24(0.60) ^d
BG	248.86(1.56) ^b	260.49(0.85) ^a	261.91(1.10) ^a	219.25(0.84) ^d	229.96(0.53) ^c	263.25(1.02) ^a	230.50(0.71) ^c
HS	176.71(0.83) ^d	194.73(0.90) ^b	201.31(0.59) ^a	181.84(0.72) ^c	180.42(0.37) ^c	193.94(2.01) ^b	175.47(0.54) ^d
BW	439.76(7.50) ^c	533.95(4.46) ^b	567.00(6.45) ^a	362.80(3.59) ^e	384.47(2.07) ^d	532.18(7.71) ^b	375.14(3.11) ^c
BL	142.20(0.88) ^c	144.98(0.53) ^b	141.08(0.68) ^c	126.14(1.52) ^e	124.91(0.39) ^e	148.04(1.41) ^a	137.77(0.87) ^d
CD	69.54(0.94) ^c	78.57(0.31) ^b	80.63(0.43) ^a	54.67(0.55) ^f	53.13(0.39) ^f	62.66(0.77) ^d	57.32(0.29) ^e
CW	39.77(0.55) ^d	45.00(0.79) ^c	51.13(0.37) ^a	37.87(0.53) ^e	36.72(0.36) ^e	47.68(0.64) ^b	39.88(0.40) ^d
HW	37.56(0.50) ^d	43.57(0.45) ^b	47.69(0.26) ^a	34.00(0.33) ^f	39.90(0.27) ^c	43.13(0.56) ^b	35.58(0.31) ^e
LHL	150.14(1.03) ^c	157.73(0.35) ^b	156.43(0.39) ^b	149.00(1.08) ^c	150.61(0.50) ^c	160.76(1.02) ^a	143.13(0.48) ^d
LFL	139.88(1.26) ^{ef}	149.93(0.45) ^b	146.76(0.40) ^c	140.55(0.91) ^e	143.46(0.53) ^d	153.46(0.87) ^a	137.79(0.39) ^f
TL	59.55(0.46) ^b	63.17(0.39) ^a	63.25(0.29) ^a	56.24(0.84) ^c	58.37(0.38) ^b	56.05(0.71) ^c	48.24(0.64) ^d
FLHC	65.07(0.41) ^c	72.75(0.36) ^a	67.84(0.89) ^b	53.60(0.61) ^e	53.00(0.42) ^e	68.92(0.90) ^b	62.66(0.84) ^d
HLHC	61.34(0.84) ^c	67.00(0.38) ^b	64.79(0.88) ^b	49.77(0.49) ^e	46.36(0.47) ^f	69.87(1.38) ^a	56.86(0.78) ^d
HC	124.42(3.16) ^b	127.89(1.46) ^{ab}	130.83(0.88) ^a	79.74(1.12) ^e	96.45(0.83) ^c	131.79(2.31) ^a	85.35(0.62) ^d
HL	36.50(0.81) ^a	29.24(0.58) ^c	30.71(0.52) ^b	19.25(0.25) ^e	21.29(0.25) ^d	35.33(0.52) ^a	20.32(0.22) ^e
NL	94.71(0.68) ^c	104.42(0.60) ^a	103.84(0.34) ^a	91.80(0.56) ^d	91.79(0.95) ^d	100.35(0.94) ^b	83.62(1.04) ^e
FCL	50.18(0.29) ^d	53.92(0.61) ^b	56.13(0.39) ^a	48.82(0.62) ^d	47.55(0.32) ^e	52.39(0.65) ^c	41.30(0.25) ^f
EL	11.86(0.08) ^a	11.26(0.11) ^b	11.87(0.08) ^a	11.22(0.13) ^b	11.40(0.11) ^b	12.13(0.09) ^a	12.11(0.09) ^a
DE	22.91(0.17) ^c	22.91(0.19) ^c	25.10(0.17) ^b	20.48(0.30) ^d	20.08(0.21) ^d	22.83(0.23) ^c	26.09(0.13) ^a

Table 5. Mean and pair wise comparison of morphological variables (cm) with their standard errors in each camel population: Aggregate gender.

Traits	Camel populations						
	Jijiga	Hoor	Gelleb	Amibara	Mille	Liben	Shinille
No.	73	70	71	71	72	68	69
HG	198.75(1.49) ^c	207.12(0.94) ^b	211.20(1.36) ^a	185.55(1.09) ^d	188.57(0.92) ^d	211.87(1.28) ^a	185.31(0.48) ^d
BG	247.13(1.50) ^c	255.73(1.35) ^b	257.30(1.42) ^b	221.95(0.95) ^e	231.32(0.57) ^d	263.69(0.89) ^a	230.54(0.60) ^d
HS	178.24(0.92) ^d	196.09(0.82) ^b	202.18(0.53) ^a	184.34(0.85) ^c	183.54(0.82) ^c	196.37(1.76) ^b	177.67(0.68) ^d
BW	440.44(7.27) ^c	519.91(5.08) ^b	550.59(6.56) ^a	380.88(5.34) ^e	402.23(4.81) ^d	546.83(7.53) ^a	383.02(3.02) ^e
BL	140.58(0.92) ^{bc}	145.91(0.49) ^a	142.83(0.69) ^b	126.77(1.25) ^d	127.49(0.54) ^d	148.30(1.24) ^a	139.94(0.82) ^c
CD	69.08(0.95) ^b	79.25(0.32) ^a	80.62(0.35) ^a	54.95(0.56) ^e	53.56(0.36) ^e	63.01(0.68) ^c	58.22(0.34) ^d
CW	39.87(0.58) ^e	46.43(0.76) ^c	51.72(0.34) ^a	38.26(0.46) ^e	38.90(0.61) ^e	48.76(0.71) ^b	41.75(0.50) ^d
HW	38.40(0.50) ^d	44.15(0.42) ^b	47.09(0.27) ^a	34.51(0.30) ^f	40.43(0.27) ^c	43.40(0.47) ^b	37.25(0.43) ^e
LHL	151.16(0.90) ^d	158.45(0.35) ^b	157.65(0.44) ^b	152.01(1.16) ^{cd}	153.54(0.90) ^c	162.62(0.98) ^a	144.10(0.45) ^e
LFL	141.33(1.08) ^d	151.05(0.46) ^b	148.62(0.57) ^c	143.23(0.99) ^d	146.42(0.87) ^c	154.92(0.84) ^a	138.84(0.40) ^e
TL	60.28(0.72) ^b	64.32(0.43) ^a	64.61(0.41) ^a	57.20(0.72) ^c	60.04(0.52) ^b	56.86(0.77) ^c	49.85(0.60) ^d
FLHC	65.31(0.51) ^c	73.30(0.35) ^a	68.62(0.75) ^b	56.02(0.77) ^d	55.00(0.60) ^d	70.62(0.83) ^b	70.67(1.83) ^b
HLHC	61.06(0.71) ^d	67.73(0.38) ^b	66.19(0.83) ^c	51.45(0.57) ^e	48.54(0.66) ^f	71.78(1.29) ^a	64.38(1.71) ^c
HC	121.17(3.06) ^c	129.74(1.26) ^b	132.88(0.87) ^{ab}	81.41(1.05) ^f	96.24(0.68) ^d	136.42(2.48) ^a	86.82(0.91) ^e
HL	35.52(0.79) ^a	30.15(0.52) ^b	31.26(0.44) ^b	19.73(0.23) ^d	21.53(0.21) ^c	35.84(0.53) ^a	20.75(0.20) ^{cd}
NL	94.40(0.85) ^c	107.49(0.90) ^a	107.48(0.92) ^a	93.59(0.71) ^c	93.74(0.91) ^c	102.05(1.14) ^b	87.48(1.15) ^d
FCL	50.41(0.37) ^c	54.78(0.55) ^b	57.05(0.41) ^a	49.58(0.53) ^{cd}	48.61(0.37) ^d	53.56(0.60) ^b	42.24(0.28) ^e
EL	11.85(0.07) ^b	11.85(0.07) ^c	11.90(0.06) ^b	11.38(0.11) ^c	11.52(0.10) ^c	12.11(0.09) ^{ab}	12.20(0.07) ^a
DE	23.21(0.17) ^c	22.78(0.16) ^c	24.98(0.14) ^b	20.63(0.25) ^d	20.47(0.19) ^d	23.14(0.21) ^c	25.94(0.11) ^a

With regard to female morphological variables, females of Gelleb camel population were significantly superior ($p < 0.05$) in HG, HS, BW, CD, CW and HW to females of other camel populations (Table 4). Females of Liben and Hoor camel populations also showed higher values in HG, HS and BW than the remaining populations. Females of Shinille and Amibara camel populations recorded significantly ($p < 0.05$) the lowest values as compared with other populations for HG, HS and BW. Jijiga female camel population had higher HG and BW than Amibara, Mille and Shinille female camel populations which are found in the sparse vegetation cover and high temperature environment. Females of Gelleb camel population recorded significantly ($p < 0.05$) higher CD, CW and HW than females of other camel populations studied. Hump length (HL) of Gelleb female camel population was significantly larger than Hoor female camel population but both of them had a similar BG within the same environment. Hoor and Liben followed that of Gelleb female camels in all the preceding morphological variables. Female camels of Amibara and Mille populations recorded the lowest ($p < 0.05$) values for CD and CW.

Mean comparison for aggregate gender (Table 5) revealed that Hoor and Liben camel populations exhibited a significantly ($p < 0.05$) longer BL than other camel populations studied. BG and HL had a positive relationship in both Hoor and Gelleb camel populations which are distributed within the same environment. Mille and Amibara camels recorded a significantly ($p < 0.5$) shorter BL than other camel populations. Gelleb followed by Liben and Hoor camel populations had significantly ($p < 0.05$)

superior morphological variables of HS, CD, CW and HW to the remaining camel populations.

Canonical and discriminant analysis

The discriminate function correctly classified 99.61% of all camels investigated. Classification of cross-validation (Table 6) indicated an average success rate at 93.05%. About 83.78%, 87.32%, 95.83%, 94.44%, 98.63%, 91.30% and 100 % for Jijiga, Hoor, Gelleb, Amibara, Mille, Liben and Shinille camels were correctly assigned into their distinct sources of origins, respectively.

All squared Mahalanobis distances within males (Table 7), females (Table 7) and aggregate gender (Table 8) of all camel populations studied were highly significant ($p < 0.001$). Among the male camel populations, the largest distance was observed between Shinille and Amibara followed by the distance between Shinille and Gelleb. Males of Shinille camel population were significantly ($p < 0.001$) distant from males of other camel populations. A relatively close Mahalanobis distance was recorded between Hoor and Gelleb followed by that between Amibara and Mille male camel populations. The greatest morphological divergences in female camel populations were observed between Shinille and Mille and between Mille and Gelleb. The least morphological divergence was observed between Hoor and Gelleb followed by that between Mille and Amibara female camel populations. The largest morphological divergence for aggregate gender was observed between Mille and Shinille followed by that between Gelleb and Mille camel populations while the least value was recorded between Hoor and Gelleb followed by that between Amibara and Mille camel populations (Table 8).

Table 6. Number of observations (before the bracket) and percentage classified (in bracket) in different camel populations using discriminant analysis.

Populations	Jijiga	Hoor	Gelleb	Amibara	Mille	Liben	Shinille
Jijiga	61(83.6)	7(9.5)	0(0.00)	0(0.00)	3(4.05)	0(0.00)	2(2.70)
Hoor	2(2.8)	61(87.1)	7(9.86)	0(0.00)	0(0.00)	0(0.00)	0(0.00)
Gelleb	0(0.00)	3(4.17)	68(95.8)	0(0.00)	0(0.00)	0(0.00)	0(0.00)
Amibara	0(0.00)	0(0.00)	0(0.00)	67(94.4)	4(5.6)	0(0.00)	0(0.00)
Mille	0(0.00)	0(0.00)	0(0.00)	1(1.37)	71(98.6)	0(0.00)	0(0.00)
Liben	2(2.90)	3(4.35)	1(1.45)	0(0.00)	0(0.00)	62(91.2)	0(0.00)
Shinille	0(0.00)	0(0.00)	0(0.00)	0(0.00)	0(0.00)	0(0.00)	69(100.0)

Table 7. Squared Mahalanobis distances between Ethiopian camel populations (values for female camels are above the diagonal while those for male camels below the diagonal).

Populations	Jijiga	Hoor	Gelleb	Amibara	Mille	Liben	Shinille
Jijiga	0	36.33	50.16	75.50	95.33	42.61	47.99
Hoor	87.17	0	12.12	90.30	95.20	38.93	70.29
Gelleb	119.86	13.80	0	87.84	96.58	44.62	77.61
Amibara	81.41	140.09	155.74	0	18.63	78.15	70.27
Mille	67.40	120.04	143.47	18.33	0	64.27	96.60
Liben	122.27	248.78	267.40	216.15	184.48	0	66.53
Shinille	495.71	504.11	620.80	621.03	561.10	510.59	0

Table 8. Squared Mahalanobis distances between Ethiopian camel populations (aggregate gender).

Populations	Jijiga	Hoor	Gelleb	Amibara	Mille	Liben	Shinille
Jijiga	0						
Hoor	25.89	0					
Gelleb	37.30	8.85	0				
Amibara	52.48	61.02	68.27	0			
Mille	65.42	62.76	72.47	12.11	0		
Liben	34.59	35.68	40.24	64.66	54.06	0	
Shinille	40.67	55.75	63.72	66.05	84.23	61.06	0

The first four most important morphometric variables for aggregate gender (Table 9) with higher Wilks' lambda and F-values (comparatively near to one) used for discriminating between camel diversity were CD, BL, distance between eyes (DE), and HS. The tolerance values obtained for these variables were greater than 0.1, indicating absence of collinearity problem among the nine most discriminating morphometric variables. The other variables such as HG, BW, HLHC, CW, ear length (EL), neck length (NL), LFL and LHL all had a Wilks' lambda relatively near to zero.

Stepwise discriminate analysis of the first five morphometric variables in females and the first six in males (Table 10) showed no collinearity problem among the variables. CW, BL and DE were important variables to differentiate the two genders. The most important traits in discriminating between females of all camel populations were CD and BG whereas FLHC and CD were the two most important traits in discriminating between male camel populations.

Table 9. Stepwise discriminant analysis for aggregate gender.

Step	Variables entered	Partial R-square	F-values	Pr>F	Wilks' lambda	Tolerance
1	CD	0.8263	391.80	<.0001	0.17365195	0.18
2	BL	0.6010	123.74	<.0001	0.06929538	0.65
3	DE	0.5191	88.52	<.0001	0.03332253	0.59
4	HS	0.5008	82.09	<.0001	0.01663537	0.51
5	BG	0.4289	61.34	<.0001	0.00949979	0.44
6	FCL	0.3233	38.94	<.0001	0.00642843	0.40
7	HW	0.2968	34.32	<.0001	0.00452067	0.38
8	FLHC	0.2432	26.08	<.0001	0.00342132	0.36
9	TL	0.2026	20.58	<.0001	0.00272828	0.34
10	BW	0.1982	19.98	<.0001	0.00218758	
11	LFL	0.2218	22.99	<.0001	0.00170234	
12	HG	0.1169	10.65	<.0001	0.00150337	
13	HLHC	0.1129	10.22	<.0001	0.00133364	
14	CW	0.0834	7.29	<.0001	0.00122242	
15	EL	0.0833	7.27	<.0001	0.00112061	
16	NL	0.0634	5.40	<.0001	0.00104960	
17	LHL	0.0597	5.06	<.0001	0.00098697	

Table 10. Stepwise discriminant analysis for female and male camel populations.

Stepwise selection summary												
Step	Females						Males					
	Variables entered	Partial R-squared	F-values	Pr>F	Wilks' lambda	Tolerance	Variables entered	Partial R-squared	F-values	Pr>F	Wilks' lambda	Tolerance
1	CD	0.85	378	<0.0001	0.14	0.15	FLHC	0.86	106	<0.0001	0.1304	0.14
2	BG	0.66	128	<0.0001	0.04	0.43	CD	0.87	109	<0.0001	0.0164	0.97
3	DE	0.56	85	<0.0001	0.02	0.40	HG	0.83	78	<0.0001	0.0027	0.90
4	BW	0.55	80	<0.0001	0.009	0.12	HS	0.69	35	<0.0001	0.0008	0.38
5	BL	0.51	69	<0.0001	0.004	0.11	DE	0.57	20	<0.0001	0.0003	0.36
6	HW	0.43	48	<0.0001	0.002		BL	0.53	17	<0.0001	0.0001	0.26
7	FCL	0.32	30	<0.0001	0.001		BG	0.41	10	<0.0001	0.0001	
8	LFL	0.28	25	<0.0001	0.001		TL	0.44	11	<0.0001	0.0001	
9	TL	0.22	18	<0.0001	0.0009		CW	0.35	7	<0.0001	0.00003	
10	HG	0.16	12	<0.0001	0.0008		LHL	0.28	5	<0.0001	0.00002	
11	FLHC	0.15	11	<0.0001	0.0006		HW	0.30	6	<0.0001	0.00001	
12	HC	0.16	12	<0.0001	0.0005		FCL	0.26	5	0.0001	0.000012	
13	HLHC	0.13	9	<0.0001	0.0005		LFL	0.21	3	0.0016	0.000009	
14	EL	0.13	9	<0.0001	0.0004		BW	0.13	2	0.0513	0.000008	
15	CW	0.10	7	<0.0001	0.0003							
16	NL	0.07	5	<0.0001	0.0003							
17	LHL	0.06	4	0.0003	0.0003							
18	HS	0.04	3	0.0056	0.0003							

Principal component analysis

Principal components and correlation circles for morphological measurements of female and male camel populations are shown in Table 11 and Figure 3. The first two principal components expressed 78% of the total variation in both genders (Table 12). The first principal component in both male and female camel populations was positively correlated with all

variables. Most of the variation in female camel populations was accounted by body length variables (BG, HG, HS, LHL and LFL) whereas variation in male camel populations was mainly determined by both body length and width variables (BG, HS, BL, CD and HW). The first two components in female camel populations were closely associated with HS, LFL and LHL.

Table 11. Weighting of each trait in the PCA analysis. Values indicate the relative (negative and positive) contributions of traits to the first two principal components 1 and 2.

Traits	Principal component 1		Principal component 2	
	Males	Females	Males	Females
HG	0.345	0.363	-0.297	-0.123
BG	0.357	0.368	-0.090	-0.181
HS	0.369	0.302	-0.007	0.319
BW	0.393	0.377	-0.144	-0.019
BL	0.184	0.276	0.530	-0.303
CD	0.199	0.313	0.495	-0.252
HW	0.237	0.297	0.371	-0.072
LHL	0.328	0.293	-0.303	0.503
LFL	0.335	0.270	-0.239	0.567
HL	0.336	0.278	0.267	-0.339

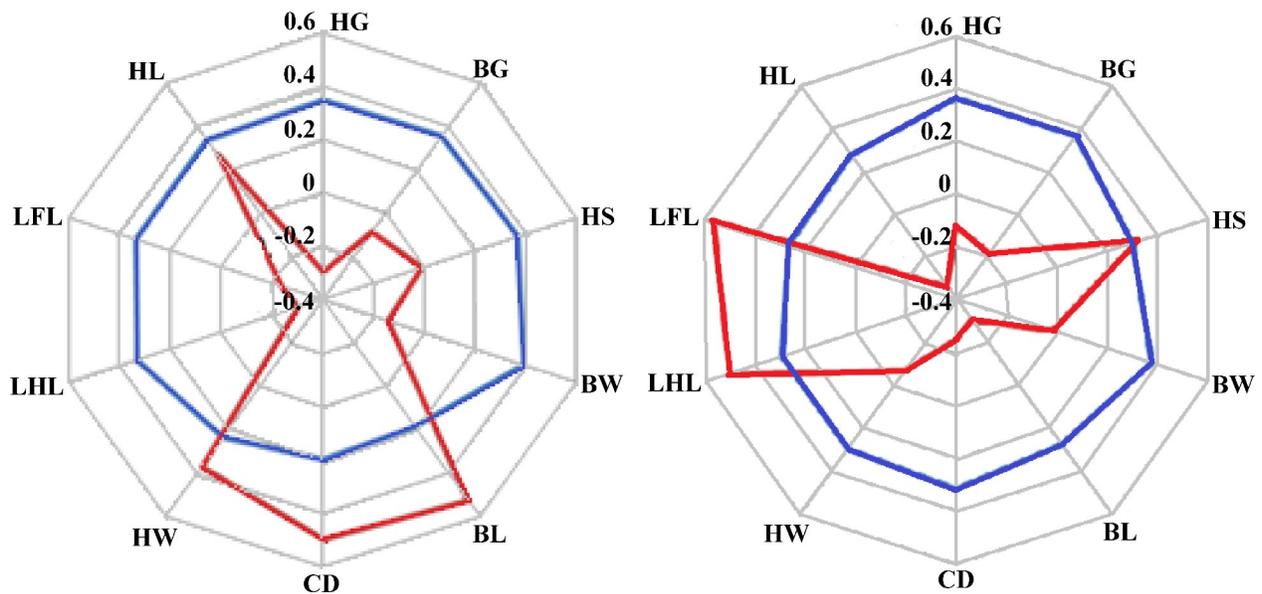


Figure 3. Correlation circles of morphological variables on the first two principal components\ (blue line for principal component 1 and red line principal component 2) (males on the right side and females the on left side).

Table 12. Eigen values and variance of the principal component analysis for body measurements.

Female camel populations				Male camel populations		
Eigen values of the correlation matrix				Eigen values of the correlation matrix		
PCs	Eigen values	Variance (%)	Total variance (%)	Eigen values	Variance (%)	Total variance (%)
PC1	6.613	66	66	5.651	56	56
PC2	1.219	12	78	2.179	22	78

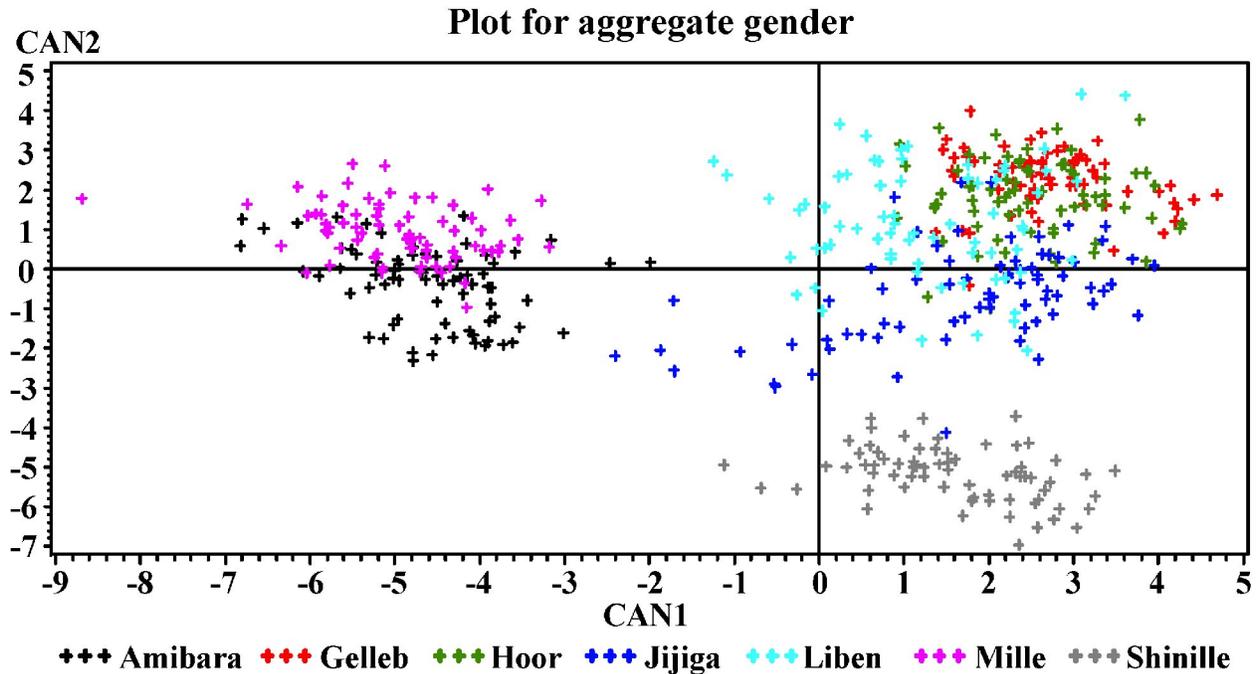


Figure 4. Plot of canonical discriminant analysis illustrating the first against the second canonical variable for all 494 Ethiopian camels.

The canonical analysis for all seven camel populations in aggregate gender allowed identifying two canonical variables (CAN1 and CAN2) which were statistically significant ($p < 0.0001$). The CAN1 and CAN2 accounted for 49.2% and 27.5% of the total variation, respectively. Figure 4 shows the results of these two canonical variables that separate all 494 Ethiopian camels. CAN1 separated two camel groups: Amibara and Mille as one group and Shinille, Jijiga, Liben, Hoor and Gelleb as another group. CAN2 also divided two groups: (1) Shinille, Jijiga and Amibara; and (2) Mille, Hoor, Liben and Gelleb.

At the final stage of classification tree in aggregate gender, the seven Ethiopian camel populations were divided into two major groups (Figure 5). The first group contained the short,

light weight camel populations (Amibara, Mille, Shinille and Jijiga) observed in the lowland ecology. The second group included the long, heavy weight, long body sized Hoor, Gelleb and Liben camel populations. Then camel populations within each group were further divided into phenotypically distinct and agro-ecologically separated sub-groups. At a distance level of 0.4 and greater, three sub-groups can be distinguished. Jijiga camel population can be treated as a separate sub-group distinct from Amibara, Mille and Shinille camel populations which are distributed in arid and semi-arid ecology with sparse vegetation cover and high temperature while Jijiga area is characterized by low temperature, better vegetation cover and wet environment. The rather close relationship between Hoor and Gelleb camel populations,

both are present in Gode area, can be explained by the mating practice followed by the communities. According to Ogden pastoral communities, crossbreds between Hoor and Gelleb camel populations exist and are named as Aiden (Figure 6, No. 6). As indicated in Table 13 and Figure 6, Jijiga and Hoor camels

have large barrel girth and udder size. Similarly, Liben and Gelleb camels have tall height and wide body size. Besides, various colors of camels were also identified in this study, including a white camel as shown in Figure 6 (No. 3).

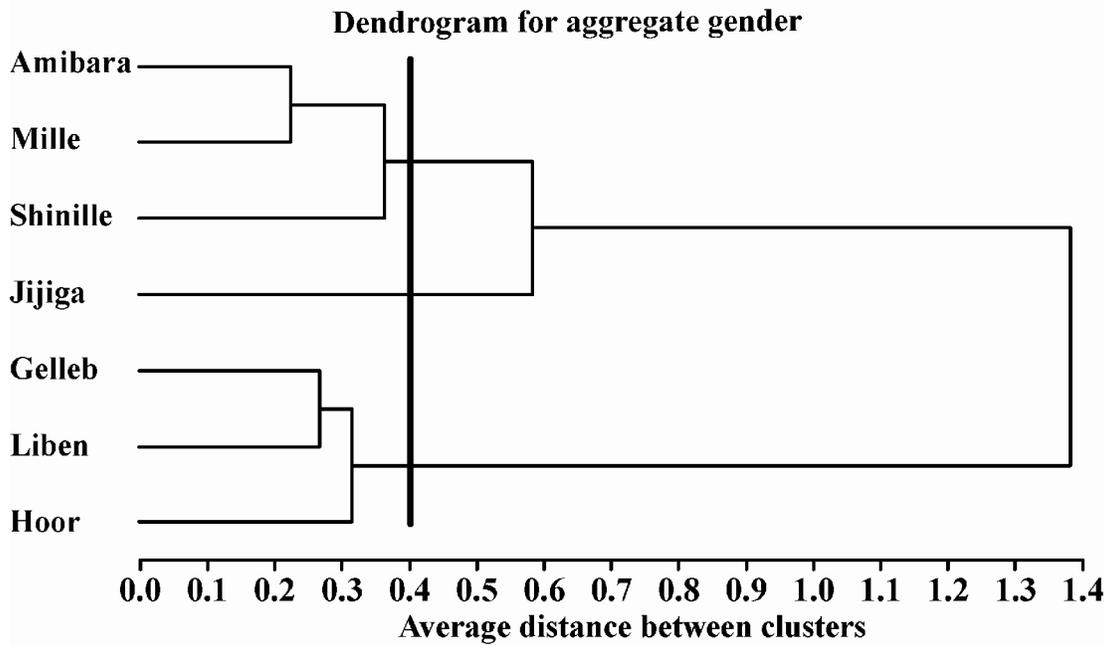


Figure 5. Hierarchical classification tree (dendrogram) of seven Ethiopian camel populations (vertical line indicates 0.4 dis-similarity).

Table 13. The five major camel groups among seven Ethiopian camel populations.

No.	Camel groups	Features
1	Hoor	Wide belly, long legs, Long body, tall height, small hip width
2	Gelleb and Liben	prominent hump, wide chest and hip, long neck and tail
3	Jijiga	Short length, medium body size and barrel girth
4	Shinille	Long ear with small body weight and heart girth, short height at shoulder, barrel girth, and short neck length
5	Amibara and Mille (Afar)	Small barrel and heart girth with small body weight, and long tail

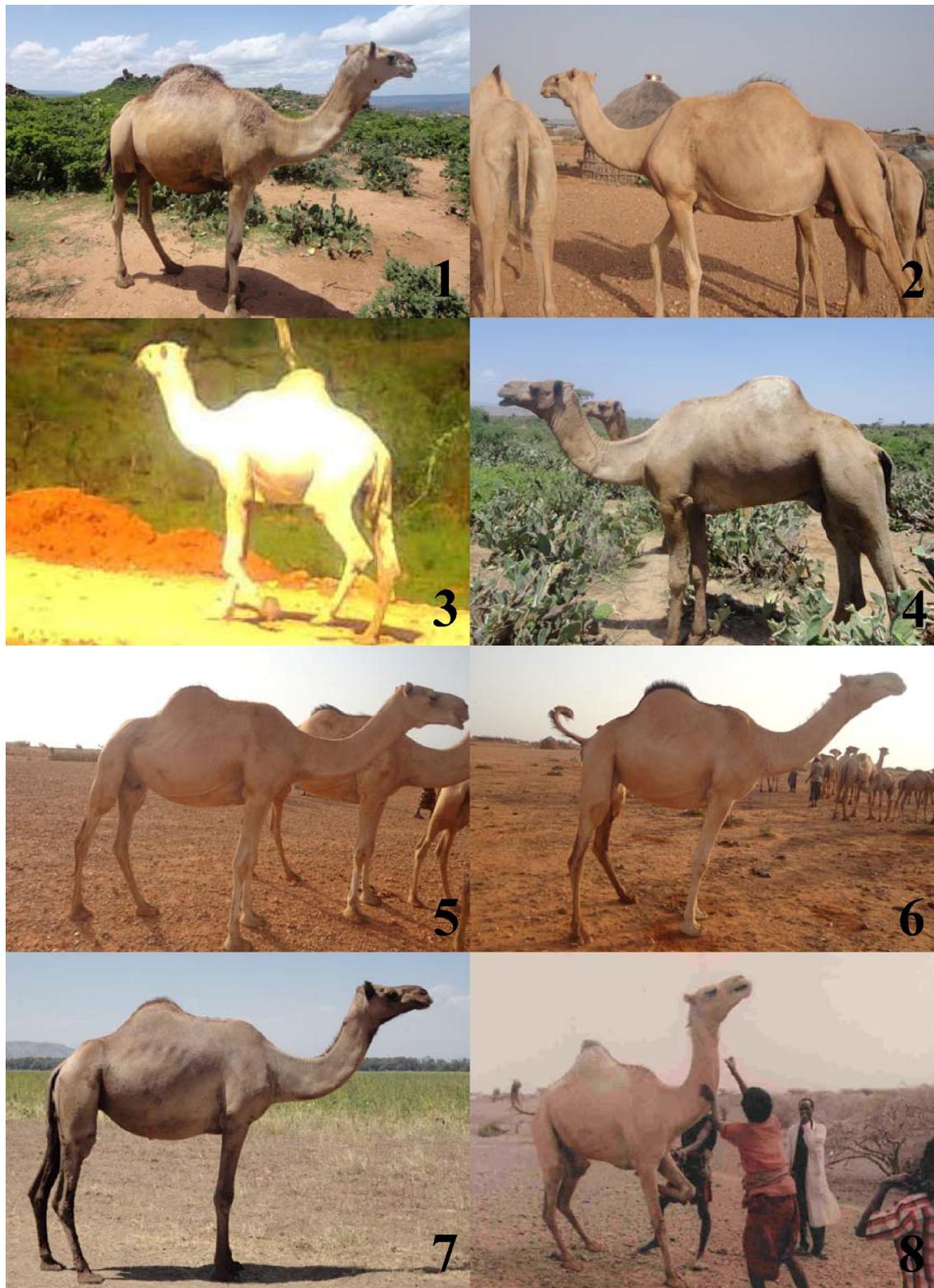


Figure 6. Camels in south, east and northeast in Ethiopia.
1 = Jijiga camel; 2 = Hoor camel; 3 = Liben camel; 4 = Shinille camel; 5 = Gelleb camel; 6 = Aiden camel; 7 = Amibara camel; 8 = Mille camel.

Discussion

The overall significantly ($p < 0.05$) superior body and morphometric length (leg, neck, ear, face, and tail), height (height at shoulder and barrel girth) and width (chest width and hip width) traits in male to female camels indicate the presence of sexual dimorphisms among the camel populations, which were also reported by Yohannes et al. (2007) and Ishag et al. (2011) in Jijiga and Sudanese camel populations, respectively. The wide chest and hip and heavy weight exhibited by Gelleb and Liben camel populations show their potential for meat production. This result is in agreement with Abebe (1991) who reported that these camels have a greater potential in terms of meat production. On the other hand, the character features of large BG, small CW and HW as well as large udder size for Jijiga and Hoor camel populations may indicate their milk production potential. Previous study noted that milk production potential of these camels is higher than Issa (Shinille) and Afar types of camels (Abebe, 1991). The different HL but similar BG in Hoor and Gelleb camel populations may be due to their difference in milk production characteristics. Hoor camel population is more suitable and preferred in most of the time for milk production than Gelleb camel population in Gode pastoral communities. It may be related with utilization of stored energy in the hump for milk production during scarcity of feed or drought periods.

The calculated average BW of Hoor, Gelleb (Ogaden) and Liben camels are higher than values reported by Manayzewal (1987), Ishag et al. (2011) and Raziq et al. (2011) for Areho type of Erythrean camel, Sudanese camel and Raigi camel from Pashtoon nomads of Afghanistan and Pakistan, respectively, but lower than the value in Muhammed (2001). The lower values of BG, HG, BW, CW and HW recorded for Amibara, Mille and Shinille camels may be attributed to the high intensity of temperature and scarcity in feed availability of the environment of origin of these populations. The morphological body structures of these camels (e.g. small body size) are important attributes for adaptation to scarcity of feed and high temperature. Shinille camels are the smallest one in Ethiopia, but it has prominent shoulders,

a deep chest and well-muscled straight legs, an indication of their capacity for draft purpose. The HG, NL and HS of this camel population are much lower than the measurements taken on Saudi Arabian camel breeds. Amibara and Mille camels are comparable in almost all measurements with values for Saudi Arabian camel breeds (Abdallah and Faye, 2012).

Significantly long hind and forelegs for Mille and Liben camels may show their adaptive long leg traits to arid areas. Moreover, the small body size and long legs may indicate the riding character of Mille camels. The presence of significantly superior TL in Hoor and Gelleb camels may indicate their adaptive nature to protect themselves from biting flies, some of which are disease causing organisms. This can be supported by the fact that the natural environment for Hoor and Gelleb camel populations is Wabe Shebele River basin, where there is a favorable condition for breeding and multiplication of the biting flies. The study of Abebe (1991) indicated that trypanosomiasis is one of the major diseases and infection of *Trypanosoma evansi* was common in Ogaden (Hoor and Gelleb) camel populations.

Squared Mahalanobis distances differ between genders. The highest phenotypic distance was observed between Shinille male camels and males of other camel populations. As noted in this study, mean values of this population are exceptionally below the average means of other populations in BW, HG, HS, BG, which make the Shinille male camels distant from others. According to the group discussion with elders in Shinille District, male camels are used for transportation of fuel wood and other activities year round, and do not accompany other herds during migration in search of feed and water. But female camels migrate during dry season for three months to other places where better feeds are available. Thus the major feed resource for camels in this area is Cactus pear (*Opuntia ficus-indica*), which is available throughout the year. However, Cactus pear has low nutrient contents especially the protein which is even below the maintenance requirement, hence can affect growth of livestock (Tegegne, 2001). In addition, ratio of Ca:P level is not negligible for appropriate skeletal development. One study on

O. polyacantha revealed that phosphorus content was below livestock dietary requirement (Shoop et al., 1997). Other study explained that phosphorus (P) is one of the essential minerals for all animals. It plays a critical role in cellular metabolism as part of the energy currency of the cell, in cellular regulatory mechanisms and in bones. Through its involvement in these metabolic and structural processes, P is essential for animals to attain their optimum genetic potential in growth as well as skeletal development (Todd and Roselina, 2008). The low nutritional quality of Cactus pear might have therefore been the major factor that negatively hampered most body measurements of Shinille male and to some extent female camels. This implies the importance of supplementing camels with additional feeds especially having high protein content in addition to Cactus pear in this area.

Squared Mahalanobis distances between Mille and Amibara and between Hoor and Gelleb camels are small in comparison with those between other camel populations in aggregate gender. The differences among these camel populations can be justified from the relatedness of ecology, management and population history.

Stepwise discriminant analysis also indicates the existence of sexual dimorphisms in camels. This result is in agreement with Ishag et al. (2011) and Abdallah and Faye (2012) who reported the presence of sexual dimorphisms in Sudanese and Saudi Arabian camels. In this study, it was possible to discriminate female camel populations through CD, BG and DE whereas male camel populations can be discriminated by FLHC, CD and HG. For aggregate gender, morphometric variables of CD, BL, DE and HS were important variables to differentiate variability within camel populations. It shows that all these variables are not affected by environment and thus describe inherent size of the variables. This result was in agreement with Kefena et al. (2011) who reported body height and body length to be more important variables to discriminate between Ethiopian donkey populations. Variations in variables like HG, HLHC, CW,

EL, NL and LHL among camel populations were due to inherent population differences.

Body length traits (HG, HS, BG, LHL and LFL) in female camels and both body length and width traits in male camels can be used as selection indicators (strong effect on variation) in present camel populations. The result of correlation estimate is comparable with that reported by Abebe et al. (2002). The positive correlation indicates that simultaneous genetic improvement in some variables can be achieved when selection is applied to other variables. It is also useful to estimate the weight of camels from correlated linear measurements, where weighing scale is not easily available.

Combining both canonical discriminant analysis at individual level (Figure 4) and hierarchical classification tree built at population level (Figure 5) based on the differences among all morphological variables in aggregate gender, five major groups can be defined among the seven Ethiopian camel populations with major features as summarized in Table 13. These classifications are largely in agreement with the shared agro-ecological similarities under which these camels are distributed (e.g. the Amibara and Mille camels) and/or the unique management practice and population history of specific camel populations. For example, elders in Ogden note that a pastoral household who owns more number of the crossbreds between Hoor and Gelleb camels in the herd is considered as prestigious. This is because of the pastoralists' belief that Aiden camels are more tolerant to high temperature, scarcity of feed and water and resistant to disease than the two parental populations. Such practice certainly facilitates a regular gene flow between these two camel populations.

Conclusion

The extent of phenotypic variation is valuable to select and utilize different camel populations based on their specific characteristics and body conformation in breeding program. The presence of different camel populations in morphology, productive, adaptive and other characters in present study may provide a basis for selection and improvement. Thus attention should be given to

exploit the performance of all camel populations based on their specialization to fulfill the current demand of camel and camel by-products in the country and also in different parts of the world. The present study can be used to understand the camel resources of the country for future genetic improvement and conservation actions.

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