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Journal of Applied Animal Research

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/taar20

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To cite this article: Patrick Baenyi Simon, Junga Owino Joseph, Joel Winyo Ochieng, Christian Keambou Tiambo, Getinet Mekuriaw Tarekegn, Eunice M. Machuka, Dorine Kabange, Katunga Musale, Arsène Mushagalusa Ciza, Roger Vumilia Kizungu & Roger Pelle (2021) Typology, management and smallholder farmer-preferred traits for selection of indigenous goats (*Capra hisrcus*) in three agro-ecological zones in the Democratic Republic of Congo, Journal of Applied Animal Research, 49:1, 423-430, DOI: 10.1080/09712119.2021.1995393

To link to this article: https://doi.org/10.1080/09712119.2021.1995393

Published online: 29 Oct 2021.

JOURNAL OF APPLIED ANIMAL RESEARCH
2021, VOL. 49, NO. 1, 423–430
https://doi.org/10.1080/09712119.2021.1995393

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Typology, management and smallholder farmer-preferred traits for selection of indigenous goats (*Capra hisrcus*) in three agro-ecological zones in the Democratic Republic of Congo

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ABSTRACT

The present study aimed to assess the typology, production management, and smallholder farmer-preferred traits in selecting indigenous goats in three agro-ecological zones (AEZs) in the Democratic Republic of Congo (DR Congo). Based on a structured survey, baseline data were recorded on 320 adults and unrelated does from 202 goat farms. Hierarchical clustering on principal components revealed three clusters in the goats studied well distinguished by double and triple kidding. Prolific goats mostly clustered into cluster two and three more represented by goats of South Kivu while 82.69% of goats in Tshopo were clustered into cluster one characterized by low reproductive performances. The Canonical Discriminant Analysis revealed that the body length was an important variable both to discriminate and to classify goats from the three AEZs. Goats from Kinshasa and South Kivu were not distanced while large distance was observed between goats from Kinshasa and Tshopo (*F*-stat, $p < 0.001$). While not subjected to any good management practices, goats were considered as a source of income and saving method in smallholder farmers' households. Adaptability, resistance to disease and prolificacy were preferred traits by farmers in selecting goats. These results give the first step in the decision-making towards goat improvement in DR Congo.

ARTICLE HISTORY
Received 21 January 2021
Accepted 15 October 2021

KEYWORDS
Canonical analysis; characterization; double kidding; environnemental adaptation; goat management

Introduction

The domestication of goats is thought to have begun as early as 10,000 years before in Southeast Asia, as revealed by the analysis of mitochondrial DNA *d-loop* region (Nomura et al. 2013). Goats have been domesticated in developing countries and play important socio-economic, nutritional and cultural roles in the rural community (Onzima et al. 2018; Monau et al. 2020). The reproductive efficiency determined by the length of the breeding season, the overall rate, the age at puberty, the age at the first service, the age at the first kidding, the litter size, the number of double and triple kidding, and the weight of kids at birth, has been one of the indicators of goats adaptation (Moaeen-ud-Din et al. 2008; Zhang et al. 2008). Besides the genetic aspects and the reproductive performances, understanding both the environmental factors and the farmer-preferred traits for animal selection is necessary for the livestock improvement programmes to succeed (Dossa et al. 2009; Mueller et al. 2015; Onzima et al. 2018).

In the Democratic Republic of Congo (DR Congo), indigenous goat populations are estimated at 4,065,709 heads spread throughout all the three agro-ecological zones (AEZs) of the country (FAO 2005; FAOSTAT 2018). Several studies have been conducted to assess the productivity and the population dynamic in Congolese indigenous goats by estimating the number of kids born by a doe in five years (Sabimana et al. 2018), the socio-economic impacts (Wasso et al. 2018) and the physiological adaptation and heat tolerance (Baenyi et al. 2020). However, little is known on the typology, the production systems and the farmer-preferred traits for selecting goats in DR Congo.

A study of the typology and the production systems management is required to facilitate improved management and conservation of goats (Lanari et al. 2003; Gama and Bressan 2011; Mekuriaw et al. 2016). The animal characterization begins with the knowledge of variation in the morphological traits followed by the characterization at the molecular level (Delgado et al. 2001). Principal Component Analysis (PCA)

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and Canonical Discriminant Analysis (CDA) have been widely applied both to classify and to discriminate goat populations from different geographic environment (Yakubu et al. 2010; Hilal et al. 2016; Arandas et al. 2017).

A combination of phenotypic information and production management yield clues about the genetic potential of livestock populations to further design tools for use in breeding programmes. This study aimed to determine the typology, production management, and farmer-preferred traits in selecting indigenous goat populations in three AEZs in DR Congo.

Materials and methods

Statement of animal rights

The study was carried out following the ethical approval and consent to interview farmers provided by: (1) the Université Evangélique en Afrique, Bukavu, South Kivu, DR Congo, under the research certificate N° FACAGRO/UEA/KK/308/18; and (2) the South Kivu provincial inspection, Ministry of Agriculture, Fishery and Livestock, Bukavu, DR Congo, under the authorization N° 55.00/004/IPAPEL/SK/2019.

Study area

This study was carried out in three regions of DR Congo that included South Kivu, Tshopo and Kinshasa and representing the three AEZs of the country. South Kivu is located in the high altitude volcanic mountains zone (east), Tshopo in the alluvial basin zone in the equatorial forest (central), and Kinshasa in the savannah or the sub-humid zone (west). Apart from the socio-economic benefits (Wasso et al. 2018) and the environmental aspects, South Kivu was chosen based on its proximity to countries bordering DR Congo: Tanzania, Rwanda, and Burundi, where commercial transactions and animal exchanges frequently occur. Tshopo was chosen based on its geographic location (the equatorial forest region), affecting goat's diversity, management and productivity. Animal exchanges and commercial transactions between Kinshasa (capital city) and other regions, including Bandundu, Kasai central, Congo Central and the reproductive performances of goats (Sabimana et al. 2018), were the major criteria for considering Kinshasa among the study areas.

Data collection

The African Goat Improvement Network (AGIN) sampling protocol for the standardized phenotyping (Session TRR 2011) was used for the data collection. All the measurements and observations (morphological traits and reproductive performances) were recorded on 320 adults and unrelated does (South Kivu, $n = 120$; Kinshasa, $n = 120$; and Tshopo, $n = 80$) distributed in 202 farms. Farmers randomly selected these animals based on the high number of kidding reported in the farm. The body measurements were taken early in the morning using a measuring tape and weighing scale.

Four quantitative traits: body weight (kg), body length (cm), height at the stern (cm), height at withers (cm) and eight qualitative traits: body hair coat colour type, facial profile, ear orientation, presence or absence of beard and tassel, horn shape, the pattern of the body hair coat and its shine were considered for morphological traits.

The reproductive performances were focused on the kidding history (number of kidding, number of double and triple kidding, number of kids weaned, litter size at the first, the second and third kidding during the period of this study) (Onzima et al. 2018; Bhattarai et al. 2019).

Information related to feeding management, health care management, reproduction management, the goat management according to the seasons, the socio-economic benefits of keeping goats, and the farmer-preferred traits in selecting goats were concidered for the understanding of the production system (Onzima et al. 2018; Bhattarai et al. 2019). This information was recorded in the 202 farms in the three AEZs studied.

Data analysis

Qualitative and quantitative traits, as well as reproductive performances, were subjected to descriptive analysis (Trochim and Donnelly 2001). Relative frequencies, mean and standard deviation of various characterization parameters were summarized in tables and figures. Chi-square statistics and Fisher's exact test were used to test the relationships between qualitative parameters (morphological) and regions.

The suitability of the dataset for clustering analysis on principal components was tested statistically using the Bartlett's test of sphericity in order to minimize the danger of interpreting factor analytic results, which can be attributed entirely to chance. We found a p-value <0.001, indicating that hierarchical clustering on principal components (HCPC) was very likely to be useful. Then, clusters were obtained using HCPC on body measurement and reproductive performances.

Canonical Discriminant Analysis (CDA) was implemented with the Candisc package version 0.8-0 computing canonical scores and vectors (Friendly and Fox 2017). The total variation explained by each canonical variable (Can) and coefficient was calculated. The scores for each Can and individual were plotted in the canonical space. The first two Can (Can 1 and Can 2) were considered in building a graph. Differences between the three regions were obtained by F-test ($p < 0.05$) over Mahalanobi's distances expressing the distance between the centroids of each group through the HDMD package version 1.1 (McFerrin and McFerrin 2013).

Mahalanobis distance $= [(\bar{\boldsymbol{X}}_{\boldsymbol{i}} - \bar{\boldsymbol{X}}_{\boldsymbol{j}})' \boldsymbol{S}^{-1} (\bar{\boldsymbol{X}}_{\boldsymbol{i}} - \bar{\boldsymbol{X}}_{\boldsymbol{j}})]^{(1/2)}$, where $\bar{\boldsymbol{X}}_{\boldsymbol{i}}$ and $\bar{\boldsymbol{X}}_{\boldsymbol{j}}$ are the mean vectors for regions $\boldsymbol{i}$ and $\boldsymbol{j}$, and $\boldsymbol{S}^{-1}$ is the inverse matrice of the sample variances and sample covariances common to all regions. The meaning of the extracted canonical variables was assessed by examining correlations between morphological characteristics and canonical variables. Statistical analyses were performed using R Statistical Software version 4.03 (R Core Team 2020).

Results and discussion

Descriptive analysis of morphological traits

Significant statistical relationships ($p \leq 0.0001$) were observed between all qualitative morphological traits and sampling regions. The dominant goats' hair coat colour type in the AEZs was black (31.26%), followed by grey (23.40%). Other dominant morphological traits were straight facial head (100%), absence of beard (88.8%), curved horn shape (91.56%), absence of tassels (94.53%), a plain pattern of the body hair coat (92.10%). Ear orientation was mostly horizontal in Tshopo (73.07%) and Kinshasa (97.36%) while erected in South Kivu (45.90%). The presence of light hair was observed on goats of South Kivu (62.27%) and Kinshasa (75.43%), while absent on goats in Tshopo (63.46%). The absence of selection through structured selective breeding can explain the variability in the morphological traits (Halima et al. 2012). Similar results were obtained in Ethiopian goat populations (Ameha 2001; Halima et al. 2012; Gebreyowhens and Kumar 2017). Black coloured goats that are believed to have a superior adaptation to seasonal cold weather or cold nights (Robertshaw 2006) were the majority in Kinshasa and Tshopo, while the two regions are among the hottest regions in DR Congo. In this case, the temperature regulation in Congolese goats could be controlled by horns, which has been considered an advantage for the drainage of blood through the cavernous sinus as a control mechanism for thermal homeostasis (Robertshaw 2006). The association of both the black coat colour and the presence of horns with the reproductive performances (Manzi et al. 2011; Halima et al. 2012; Monau et al. 2018) could explain the predominant of the black coloured and horned goats in Congolese goat populations since prolificacy was mentioned as one of the preferred traits in selecting goats by farmers.

Descriptive analysis of quantitative (body measurements) traits and reproductive performances

High body length and body weight were recorded on goats from Kinshasa (Figure 1B) and South Kivu (Figure 1C). High height at withers and stern were recorded on goats of the Kinshasa region, followed by goats of South Kivu. The goats of the Tshopo region (Figure 1A) had the lowest values for all measured morpho biometric traits compared to goats of Kinshasa and South Kivu (Table 1). Peters and Horst (1981) suggested that body size is a suitable criterion for the classification of goats since it gives clues to potential performance. Accordingly, and based on the observations of Devendra and Burns (1983), classifying tropical goats into three groups that include large (>65 cm at witchers), small (51–65 cm at witchers) and dwarf (<50 cm at witchers), Congolese indigenous goats could be classified into the small goats (53.55 ± 5.19 cm for goats of South Kivu; 55.25 ± 4.13 cm for goats of Kinshasa) and into the dwarf goats (47.69 ± 1.76 cm for goats of Tshopo).

The average number of kids born per kidding increased from the first to the third parity in all the three regions. Increasing in the average number of kids born by the stage of kidding has been mentioned in Creole goat with an average litter size of 1.7 kids at the first kidding and 2.4 kids at the sixth kidding (Alexandre et al. 1999). A similar scenario was observed in black Bengal goat under semi-intensive management with an average litter size of 1.29; 1.71; 1.87; and 2.17 respectively at the 1st, the 2nd, the 3rd, and the 4th parity (Chowdhury et al. 2002). In this study, a litter size of 2 kids per parity was observed at the third kidding in indigenous goats of Kinshasa (1.80 ± 0.00) and South Kivu (1.93 ± 0.00). However, litter size of 2 kids at the second kidding and 3 kids at the sixth kidding with the probability of 6.8% of the total number of plain females were recorded in females goats raised in Banza Ngungu district in the Savanah and sub-humid AEZ in Kongo central province in DR Congo (Sabimana et al. 2018). The number of double kidding was higher than triple kidding in all the three Congolese indigenous goat populations. Similar results were observed by Đuričić et al. (2012) in Boer goats in a moderate climate zone in Croatia. Since the production system and the management of goats in the three AEZs of this study is almost the same, the reproductive performance differences between the goat populations may be justified by the genetic potential that could be influenced by the environment (Pamo et al. 2007).

Typology of goat populations

The HCPC analysis based on the morpho-biometric traits and reproductive performances has grouped the indigenous goat populations of the three studied regions into three clusters (Figure 2). Based on the regions, the PCA has indicated that the two axes showed up to 66% of the observed variability between the goat populations (Figure 3). The first axis, which retained 51.2% of the total inertia, was represented by the reproductive performances (the number of double and triple kidding) and body weight. The second axis, which retained 14.8% of the total inertia, was represented mainly by the morpho-biometric traits. When the body measurements were considered, clusters two and three were characterized by large and heavy animals compared to cluster one. Accordingly, 42.98% and 35.96% of goats from Kinshasa were clustered into cluster two and cluster three. 37.22% of goats from South Kivu were represented in cluster three, while 82.69% of goats from Tshopo were clustered into cluster one (Figure 4). Based on body measurements, two clusters were obtained in Burudian

Figure 1. Goats of DR Congo. (A) goat from the alluvial basin, equatorial forest (Tshopo province), (B) goats from the savannah plateau (Kinshasa province) and (C) goat from the high-altitude volcanic mountains (South Kivu province).

Table 1. Mean and Standard deviation (SD) of morpho biometric traits and reproductive performances of indigenous goat breeds in 3 AEZs of DR Congo.

Variables	South Kivu Mean ± SD	Tshopo Mean ± SD	Kinshasa Mean ± SD
Morpho biometric traits			
Body length (cm)	61.95 ± 5.52	51.50 ± 2.04	61.72 ± 4.37
Height at withers (cm)	53.55 ± 5.19	47.69 ± 1.76	55.25 ± 4.13
Height at stern (cm)	50.71 ± 4.86	46.68 ± 1.87	52.50 ± 3.75
Body weight (kg)	32.75 ± 6.04	30.34 ± 5.09	33.23 ± 4.04
Reproductive performances			
Estimated age (year)	3.34 ± 1.48	2.05 ± 0.73	2.56 ± 1.12
Number of kidding	3.85 ± 1.71	1.96 ± 0.94	2.52 ± 1.21
Double kidding	2.01 ± 1.1	0.88 ± 0.80	1.47 ± 1.05
Triple kidding	0.66 ± 0.90	0.04 ± 0.19	0.32 ± 0.74
Number of kids wened	2.92 ± 1.61	1.36 ± 1.06	2.23 ± 1.73
Litter size at the last kidding	1.93 ± 0.00	1.31 ± 0.12	1.80 ± 0.00
Litter size at the second kidding	1.59 ± 0.07	1.06 ± 0.14	1.32 ± 0.09
Litter size at the first kidding	1.47 ± 0.77	0.84 ± 0.82	1.12 ± 0.88

Notes: cm = centimeter; SD = standard deviation.

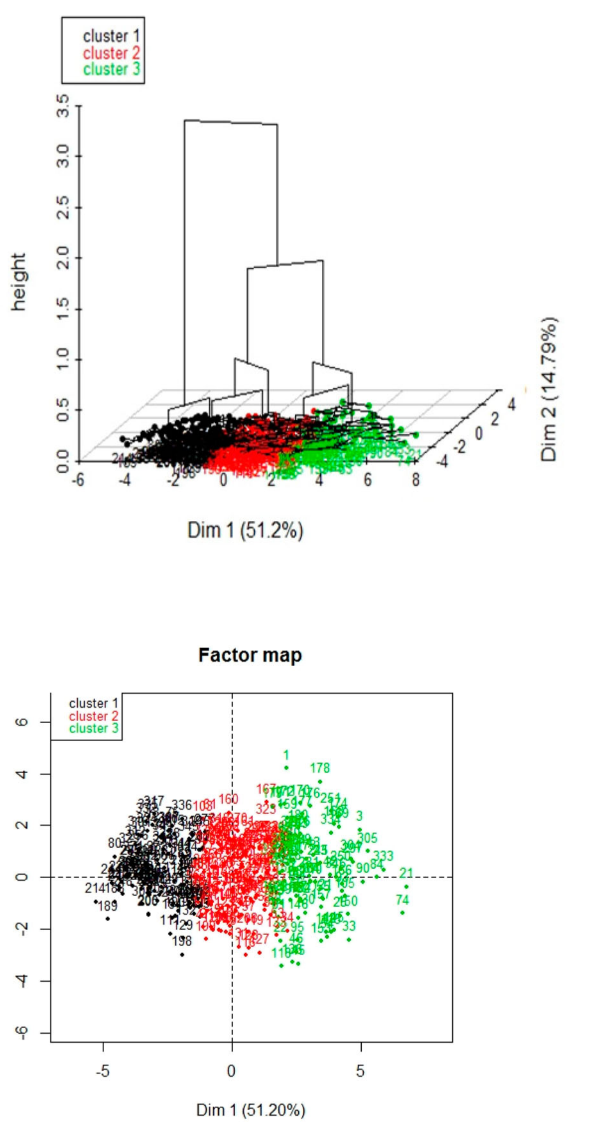

Figure 2. Hierarchical clustering based on morpho biometric traits and reproductive performances.

goats from where heavier and greater goats were mostly found in lowlands than in highlands that was characterized by slight goats (Manirakiza et al. 2020).

The reproductive performances, including double and triple kidding at three levels of kidding, have differentiated better the goats in the three studied populations (Figure 3). The number of kids born per parity has been reported in different domestic animals and production systems as a factor with economic importance leading to their breeding by farmers (Chowdhury et al. 2002; Moaeen-ud-Din et al. 2008; Ahuya et al. 2009). In this study, HCPC analysis revealed that prolific goats (with a high number of double and triple kidding) were more clustered into the clusters 2 and 3, more represented by goats of South Kivu (48.33% in cluster two, 37.22% in cluster tree) and the goats of Kinshasa (35.96% in cluster two and 21.05% in cluster 3) (Figure 3). The market price of live adult goat in Kinshasa (USD 58.42 ± 10) and in South Kivu (USD 52.05 ± 11.8) compared to the price of goat in Tshopo (USD 46.63), as demonstrated in this study, could encourage the desire of improving goat prolificity and increasing goat productivity (Vandercasteelen et al. 2018). Both the commercial transaction and the exchange of animals in South Kivu and Kinshasa may favour improving the reproductive performances by selecting prolific goats and/or cross-breeding with exotic breeds.

Although the body measurements did not explain the three clusters of goats well, they were important factors discriminating the goats in the three geographic regions (Figure 4). The CDA revealed that canonical variables presented the highest weights for body length and wither height, showing that body length is important to discriminate and classify goats from the three different regions. The first two canonical variables explained 100% of the total variation with 73.61% (Can 1) and 26.39% (Can 2). The pairwise Mahalanobis' distances and probability of a significant (*F*-test) effect of contrasts between indigenous goats from the three regions revealed that the smallest distances were observed between goats of Kinshasa and goats of South Kivu with a non-significant probability ($p = 0.0937$). The largest distances were observed between goats from Kinshasa and Tshopo or South Kivu and Tshopo (Table 2). The body measurements have been revealed to be important factors discriminating the goat populations in various geographic areas (Yakubu et al. 2010; Hilal et al. 2016; Arandas et al. 2017). In two indigenous goats in Nigeria, the rump height followed by the body length were the most discriminant variables between the two goat populations (Yakubu et al. 2010).

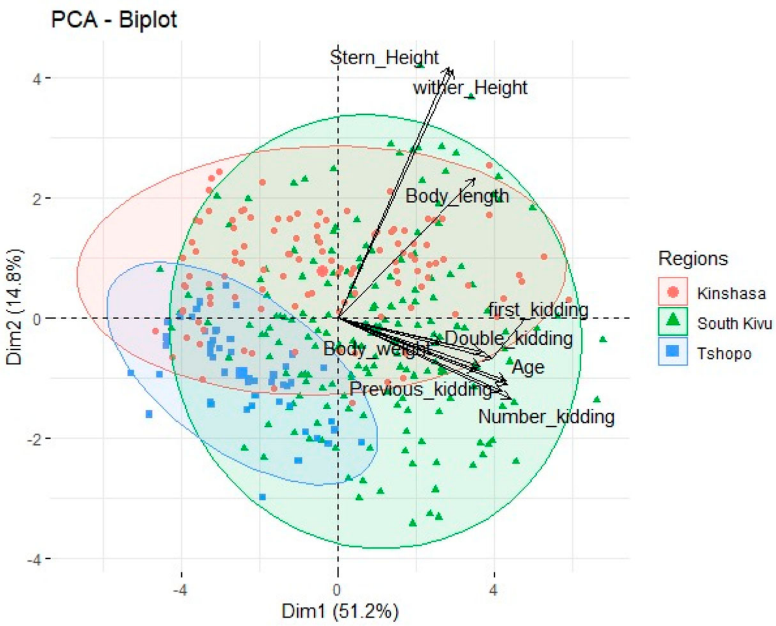

Figure 3. Principal component analysis based on morpho biometric traits and reproductive performances.

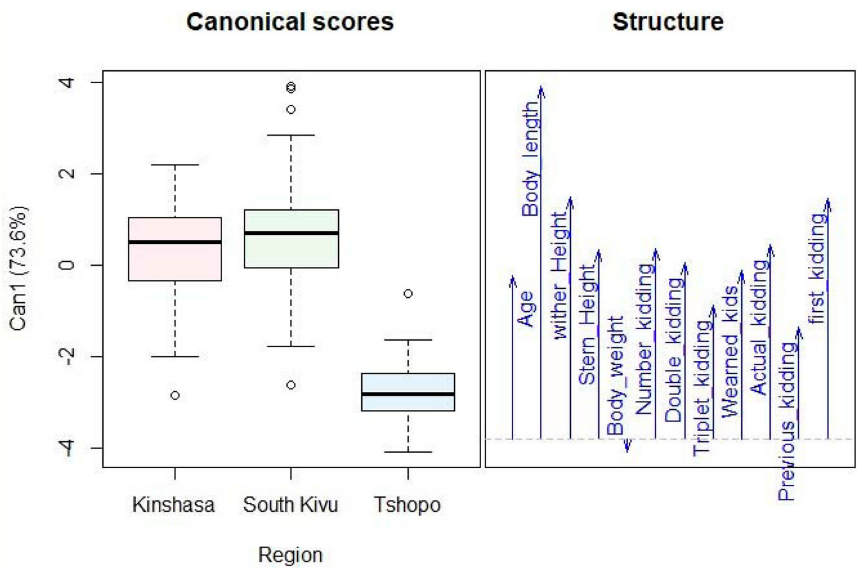

Figure 4. Canonical representation of the morphometric traits and reproductive performances associated with individuals by state.

Table 2. Pairwise Mahalanobis' distances and probability values for the contrasts between local goats from different regions in DR Congo.

Regions	Kinshasa	South Kivu	Tshopo
Kinshasa	0.00	4.73	14.58
South Kivu	ns	0.00	14.48
Tshopo	***	***	0.00

Notes: The squared Mahalanobis' distances are above the diagonal line. The probability values for the contrasts by the *F*-test (****P* < 0.001 and ns = Non-significant) are below the diagonal line.

Production management and benefits of keeping goats

In the three AEZs studied, free-grazing was the common method used by farmers to feed goats. This practice was observed more in Tshopo (100%) than in South Kivu (89.87%) and Kinshasa (54.90%), where the feeding system was supplemented by kitchen residues (29.41%). In all the three AEZs, no technical input was applied in the management of the production system, neither for the goat health care nor for the reproduction during different seasons. Keeping indigenous goats was considered by farmers as a source of income in South Kivu (98.73%) and Tshopo (90.27%), while in Kinshasa, it was mostly considered as a saving method (60.78%). For that purpose, only live adult goats were fully marketed (100%), mainly in local markets in Tshopo (98.61%) and South Kivu (81.013%) and urban markets in Kinshasa (88.23%). The price of goats was significantly ($p < 0.0001$) higher (USD 58.42 ± 10) in Kinshasa than in South Kivu (USD 52.05 ± 11.79)

Table 3. Description of important traits assisting the choice of doe raised by farmers.

Important traits	Frequency (%)		
	South Kivu	Tshopo	Kinshasa
Body conformation	0.00	1.923	1.754
Weight	0.455	1.923	0.00
Adaptability in the region	45.455	1.923	5.263
Adaptability and resistance to disease	15	13.461	38.592
None	0.00	1.923	3.509
Ability in protecting kids	0.00	3.846	4.386
Ability in protecting kids and resistance to disease	0.00	19.23	0.00
Prolificacy	0.455	7.692	0.87
Prolificacy and adaptability	6.364	5.773	0.87
Prolificacy, adaptability and resistance to disease	27.727	3.846	30.70
Prolificacy, ability in protecting kids, resistance to disease	0.00	7.692	11.40
Resistance to disease	0.455	15.384	0.00
Prolificacy and resistance to disease	4.091	9.615	0.87
Prolificacy and ability in protecting kids	0.00	5.769	1.754

and in Tshopo (USD 46.63 ± 9.68). The high price of live goats in Kinshasa could be due to the fact that it is the capital city and has almost one-fifth of the country's estimated population estimated at 90 million, while Tshopo is in the remote forest area. Vandercasteelen et al. (2018) have demonstrated that the effects of prices and intensification measures are lower for farmers in rural areas in secondary towns compared to bigs cities. The importance of livestock in generating income for farmers has been reported in other studies in developing countries (Okeno et al. 2011; Kugonza et al. 2012; Wendimu et al. 2018). Although the production management, including the production system, the breeds and the management of the production environment, positively influence the productivity of domestic animals (Thornton 2010), no management under the local production system was reported in keeping goats in the three AEZs of this study. This finding corroborates the report on goat production systems in the Assosa zone in Ethiopia (Wendimu et al. 2018) and Southern Africa (Mamabolo and Webb 2005). Feeding system by free-grazing constitutes a source of diseases to animals, causing some crucial losses of the high reproductive performances through genetic erosion, reducing the adaptative values (loss of genetic diversity) and reducing the opportunities for efficient utilization (Hassen et al. 2012; Lamy et al. 2012; Agossou et al. 2017). However, García et al. (2012) shown that, if managed adequately, free-grazing can be a useful tool for environmental conservation.

Description of farmer-preferred traits in the selection of goats

The involvement of farmers in assessing breeding objectives and designing programmes is crucial for the success of livestock improvement programmes (Dossa et al. 2009; Mueller et al. 2015). To rank animals in a relatively objective and accurate manner, farmers focus on some preferences based on weightings or indices, becoming a powerful tool for them (Onzima et al. 2018). This participatory approach of farmers is important and has been used in some developing countries to provide information for developing breeding objectives for different species, including Nile tilapia (Omasaki et al. 2016), sheep and goats (Edea et al. 2012; Gebreyesus et al. 2013) in Ethiopia, Maasai sheep (König et al. 2016) and dairy goats (Bett et al. 2009) in Kenya.

Whether based on an individual, a family, or a pedigree, selection depends on the economically important traits, e.g. meat, milk, disease resistance, drought tolerance, prolificacy, adaptability in the environment of production (Bhattarai et al. 2019). This study shows that adaptability in the region, disease resistance, prolificacy, and ability of doe to breastfeed and protect her kids up to the weaning age were mentioned as preferred traits in selecting indigenous goats to keep by smallholder farmers. The frequency of these traits varied according to the region (Table 3). In Kinshasa, 38.592% of smallholder farmers prefer adaptability and disease resistance traits, while 30.7% of smallholder farmers in the same region preferred both the prolificacy and adaptability to the region and the disease resistance. In South Kivu, the adaptability to the region (45.45%), and both the prolificacy, adaptability and the disease resistance (27.72%) were preferred traits by farmers. In Tshopo, farmers mainly considered the ability of does to protect kids and to resist diseases (19.23%). Similar findings were reported to support indigenous goat breeds selection in Uganda (Onzima et al. 2018), in Somalia (Marshall et al. 2016), in Ethiopia (Gizaw et al. 2010), and in West African dwarf goats (Ogah 2016). In all the three AEZs of this study, the adaptability trait was mentioned by farmers. It is important to highlight that the understanding and the inclusion of the adaptability traits in the breeding programme is critical for developing sustainable improvement programmes for indigenous goats (Monau et al. 2020). However, selection for adaptability traits may be more complicated unless they are positively associated with the production performances of animals (Onzima et al. 2018). From this perspective, farmers from the three AEZs studied included the prolificacy trait, especially the number of kids per parity and the ability of the doe to breastfeed (enough milk) and to protect her kids' production traits in the selection of goats to keep. Farmers could mention the adaptability traits in these regions according to the limited inputs (agro-inputs, access to professional veterinary services, capacity building in goat farming) characterizing the production systems (Wasso et al. 2018). In addition, the superiority of indigenous goat breeds to exotic breeds in terms of survival and economic performance in their local environment (Ayalew et al. 2003; Onzima et al. 2014), the ability to valorize low-quality feed resources, to resist diseases and environmental stress compared to exotic breeds (Philipsson et al. 2011; Kugonza et al. 2012), could explain the adoption by the farmers in selecting goats.

Conclusion

Goats from three AEZs of DR Congo were characterized by the black coat colour and curved horn. They clustered into three groups as a result of the number of double and triple kidding. Clusters two and three, characterized by goats with high number of double and triple kidding, were represented mainly by goats from South Kivu and Kinshasa, while cluster one was characterized by a low number of double and triple kidding included goats from Tshopo. The CDA revealed that canonical variables presented the highest weights for body length and wither height, showing that body length is important to discriminate and classify goats from the three different regions. Goats were considered as a source of income and savings method contributing to farmer's household income. However, no technical inputs were supplied in the management (feeding, reproduction and healthcare) of goats by smallholder farmers in the 3 AEZs. The adaptability to the regions, the disease resistance and the prolificacy were the most farmer-preferred traits in selecting goats. These results indicate the first step in the decision-making towards goat improvement in DR Congo. Molecular characterization by genotyping and genomics association analyses should be considered to elucidate whether the observed phenotypic differences, are genetically based and/or environmentally influenced.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by the BecA-ILRI Hub Program and ILRI through the Africa Biosciences Challenge Fund (ABCF) Program. The ABCF Program is funded by the Australian Department for Foreign Affairs and Trade (DFAT) through the BecA-CSIRO partnership; the Syngenta Foundation for Sustainable Agriculture (SFSA); the Bill & Melinda Gates Foundation (BMGF); the UK Department for International Development (DFID) and the Swedish International Development Cooperation Agency (Sida).

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