University of Natural Resources and Life Sciences, Vienna

Department of Sustainable Agricultural Systems

Division of Livestock Sciences

Design and implementation of community-based local cattle breeding programs in Burkina Faso

Dominique Ouédraogo

Dissertation for obtaining a doctorate degree (Dr.nat.techn.)

Vienna, November 2020

Main supervisor

Univ.Prof.Dipl.-Ing.Dr. Johann Sölkner

University of Natural Resources and Life Sciences (BOKU), Department of Sustainable Agricultural Systems, Division of Livestock Sciences (NUWI), Vienna, Austria

Co-supervisors

PD Dipl.-Ing.Dr. Maria Wurzinger

University of Natural Resources and Life Sciences (BOKU), Department of Sustainable Agricultural Systems, Division of Livestock Sciences (NUWI), Vienna, Austria

Assoc.Prof.Dr. Gábor Mészáros

University of Natural Resources and Life Sciences (BOKU), Department of Sustainable Agricultural Systems, Division of Livestock Sciences (NUWI), Vienna, Austria

Dr.med.vet. Pamela Anna Burger

University of Veterinary Medicine (Vetmeduni), Department of Interdisciplinary Life Sciences, Research Institute of Wildlife Ecology, Vienna, Austria

Assoc.Prof.Dr. Albert Soudré

Université Norbert Zongo (UNZ), Unité de Formation et de Recherche en Sciences et Technologies (UFR/ST), Koudougou, Burkina Faso

Statutory Declaration

I hereby declare that I am the sole author of this work. No assistance other than that which is permitted has been used. Ideas and quotes taken directly or indirectly from other sources are identified as such. This written work has not yet been submitted in any part.

Vienna, 25.11. 2020

Dominique Ouédraogo, MSc.

Table of contents

List of Tables

List of Figures

List of Appendices

List of Abbreviations

AAT African Animal Trypanosomosis

ADC Austrian Development Cooperation

AnGR Animal Genetic Resources

APPEAR Austrian Partnership Program in High Education and Research for Development

BLUP Best Linear Unbiased Prediction

BTC Belgium Technical Cooperation

CBBP Community-Based Breeding Program

CCMD/BRE Centre de conservation et de multiplication du bétail ruminant endemique de Médina Diassa

CIRDES Centre International de Recherche-Développement de l´Elevage en zone Subhumide

CMAP Centre de Multiplication des Animaux Perfromants

DAD-IS Domestic Animall Diversity – Information System

FAnGR Farm Animal Genetic Resources

FAO Food and Agriculture Organization

FAOSTAT Food and Agriculture Organization Statistics

GLM General Linear Model

INERA Institut de l´Environment et de Recherches Agricoles

INSD Institut National de la Statistique et de la Démographie

MAF Minor Allele Frequency

NGO Non-Governmental Organization

PCA Principal Component Analysis

PROGEBE Projet de Gestion Durable du Bétail ruminant Endemique

PROCORDEL Programme de Concertation de recherche-Développement de l´Elevage en Afrique de l´Ouest

ROH Runs of Homozygosity

SMB Sedentary Mixed Breed

SNP Single Nucleotide Polymorphism

SPB Sedentary Pure Baoulé

TZC Transhumant Zebu and Crossbreds

Dedication

In memory of my friends, Ouattara San Bertrand and Traoré Youssouf, both passed away during the period of this study.

May their souls rest in peace.

Acknowledgements

This work was funded by the Austrian Development Cooperation (ADC) through Austrian Partnership in High Education and Research for Development (APPEAR) Project 120: LoCaBreed "Local Cattle Breed of Burkina Faso – Characterization and sustainable use". May my gratitude and thanks be accepted.

I am thankful to Mrs. Elke Stinnig from APPEAR and Mrs. Sandra Wallgram from OeAD regional bureau in Vienna for their continued support and guidance. The visit of Mrs. Elke Stinnig in the field in Burkina Faso in September 2019 is particularly appreciated.

I would like to express my deep esteem and honest gratitude to my main supervisor, Prof. Johann Sölkner for his guidance and support during this study. From field to office, he taught me the "art" of breeding with simplicity, patience and rigor. Hans, thank you for transmitting to me your passion for animal breeding. More than a mentor, you are a model for me.

I am particularly grateful to my co-supervisors, Dr Maria Wurzinger, Dr Gabor Meszaros for their teaching in Animal Breeding and Genomics, their advices and valuable comments and suggestions in the preparation of this thesis. Dr Pamela Burger strongly supported me during the genomics data analysis. She also contributed to make my stay in Austria unforgettable. I will always remember the Christmas party celebrated with her wonderful family and our memorable visit in her village. Pamela, thanks to you and your family for your kindness and your hospitality.

Dr Albert Soudré, country coordinator of LoCaBreed, particularly showed great coordination ability as well as active involvement in field activities. This was absolutely necessary. His valuable comments on this thesis are also appreciated. Thank you for everything.

I would particularly like to thank Dr Negar Kayatzadeh, former post-doctoral researcher in the Animal Breeding Group for her invaluable support in data analysis. Even when she left for her new position in Switzerland, she stayed available, sometime, spending her weekend in guiding me and my colleagues to run various software tools. Negar, this achievement is also yours.

I wish to extend my gratitude to all the other members of LoCaBreed team. Dr Traoré Amadou, Dr Ouédraogo-Koné Salifou, Dr Traoré Lassina, Dr Ouédraogo Gisele, M. Sanou Moumouni for the family spirit and the enthusiasm we shared, specifically during our field trips. My deepest esteem goes to Dr Salifou Ouédraogo-Koné for his support, advices and generosity. Salifou, thanks for the good mood you always shared.

I express my gratitude to my colleagues PhD students in the LoCaBreed project Zoma Bienvenue Lassina and Yougbaré Bernadette. This thesis would never have been possible without their collaboration and support. I am also thankful to the Master students Zongo Pierre, Gandéma Abdoul Kader, Koné Amidou for their contribution in data collection.

I also acknowledge the government extension workers and all the farmers in the study area; Kambou Hippolyte, Bonzi Nazi, Ouédraogo Nöélie in Bouroum-Bouroum, Traoré Fousséni in Loropéni, Traoré Oumar in Kampti for their cooperation and facilitation.

I am also very grateful to all my friends and colleagues of the Animal Breeding Group who have supported me all these years. Dr Solomon Tufa, Dr Wilson Nandolo, Dr Wilson Kaumbanta, Maulana Naji, Lisa Rienesl, Brian Babimigura, Maud de Kinderen, Natahlie Schwaiger many thanks for the nice time and experience we shared. I will always remember our coffee break.

I particularly acknowledge all my Burkina Faso compatriots and fellows in Vienna. Sorgho Blaise, Ido Josue, Compaoré Serge Wilfried, Sanfo Mariam, Sanon Vincent Paul, Tapsoba Arnaud Stéphane, Derra Kiswendsida Mike, thanks for making me feel at home.

A very special appreciation is due to my extraordinary friends and colleagues in Burkina Faso. Dr Tankoano Boalidoa, Dr Inoussa Compaoré, Dr Séré Modou, Dr Lassina Sanou, Dr Aboubacar Coulibaly, Tankoano Prudence, Sodré Etienne for their moral support and encouragement.

Sincere appreciation and gratitude are going to to my father Emanuel, my mother Marie, my brother Bernard, my sisters Joanna, Christianne, Isabelle and Bénéwendé Caroline. You have been source of motivation, inspiration and strength in my career until now. Thanks for love and prayers.

A special gratitude is due to my wonderful wife Mariam Yaméogo for her love, patience and support. Thank you for accepting endured my long absence. My sincere appreciation goes to my mother in law Fanta Yaméogo/Traoré for her prayers and support.

Finally, I wish to thank all the people not cited who have contributed directly or indirectly in the completion of this thesis.

Abstract

In developing countries, lack of appropriate breeding strategies is a constraint limiting livestock genetic improvement. Community-based breeding programs try to overcome this constraint by participatory approaches at village level. This relatively recent approach has been successfully implemented for populations of small ruminants in diverse regions of Africa but is still not common in cattle. The aim of this thesis was to design and implement community-based breeding programs for local cattle in southern Burkina Faso. Firstly, we investigated cattle production systems and trait preferences of farmers related to breeding objectives and their breeding practices. Based on breeds and herd mobility, sedentary pure Baoulé, sedentary mixed breed and transhumant Zebu and crossbred systems were defined. The most important criteria for selection among the production systems were growth rate and body size. Selection of breeding males within herds and castration of non-selected bulls were among the main breeding practices. Community-based breeding programs aiming to improve body size and trypanotolerance were implemented. In these programs, participatory selection of breeding bulls was the key activity, with a committee of farmers making the final decision. Farmers used additional traits like coat color, horns shape and the suitability of bulls for ploughing in the selection of breeding bulls. To investigate the genetic structure, admixture and inbreeding levels of the breeding populations, we used high throughput genomic data. Two ancestries, i.e taurine and zebuine, were found with some level of admixture in all populations, also the presumably pure taurine population suggesting gene flow occurring among these populations. The levels of inbreeding were low to moderate and were close to those found in well-managed European breeds. Finally, we reviewed cattle genetic improvement in West Africa with a focus on six cases of local cattle breeding programs. Various breeding schemes including close, open and dispersed nucleus, village breeding were implemented to improve meat and milk production and trypanotolerance ability. Definition of realistic breeding objectives, involvement of farmers and stakeholders, infrastructural issues, funding system and lack of support of local governments were major limitations to the sustainability of some of these programs. Overall, the studies of this thesis proved that community-based breeding programs can be successfully implemented in cattle. Farmers accepted the rationale of strict selection of male animals in the community being critical for genetic gain and were active in the implementation of the breeding programs. Still, their sustainability will depend on the continued engagement of key stakeholders, including government officials as well as members of the project team.

Zusammenfassung

In vielen Ländern des Globalen Südens gibt es praktisch keine funktionierenden Zuchtprogramme zur Verbesserung lokaler Nutztier-Rassen. Dörfliche Zuchtprogramme mit Einbindung der Tierhalter in allen Stufen sind ein recht neuer Ansatz, der bei Schafen und Ziegen in mehreren afrikanischen Ländern erfolgreich umgesetzt wurde. Ziele dieser Arbeit waren Design und Implementierung dörflicher Zuchtprogramme für lokale Rinder-Populationen im Süden von Burkina Faso. Dazu wurden zuerst die bestehenden Produktionssysteme analysiert und die Tierhalter zu ihren Merkmals-Präferenzen und Zuchtstrategien befragt. Drei Systeme wurden erkannt, sesshaft mit Baoulé Rindern, sesshaft mit Baoulé x Zebu und migrantisch mit Zebu oder Baoulé x Zebu. In allen drei Systemen waren Körpergröße und rasches Wachstum der Rinder die entscheidenden Zuchtziele der Tierhalter. Hier muss bedacht werden, dass Baoulé besonders kleinwüchsig, aber tolerant gegenüber Trypanosomose (Schlafkrankheit) sind, Zebu Rinder deutlich größer, aber Tryanosomose-anfällig. Selektion der männlichen Zuchttiere aus der eigenen Herde war gängige Praxis, ebenso wie Kastration von nicht für den Zuchteinsatz benötigten Bullen. Dörfliche Zuchtprogramme zur Verbesserung der Körpergröße und Trypanosome-Toleranz wurden implementiert. Die Selektion männlicher Tiere für die Zucht war die Schlüsselaktivität. Ein Komitee der Tierhalter entschied aufgrund von Daten zum Wachstum, bezog aber auch Kriterien wie Fellfarbe und potentielle Eignung eines Bullen für die Pflugarbeit ein. Mehr als 50.000 genetische Marker wurden analysiert, um Informationen zur genetischen Struktur, Inzucht und Kreuzung zu erhalten. Taurine und zebuine Genanteile wurden in allen drei Systemen gefunden, auch im sesshaften Baoulé System mit vermeintlich rein tauriner Rasse. Schließlich wurden sechs Zuchtprogramme mit lokalen Rinderrassen in Westafrika reviewt. Nukleuszuchtprogramme (offen und geschlossen) und die in dieser Arbeit implementierten dörflichen Zuchtprogramme wurden verglichen. Realistische Zuchtziele, Einbeziehung aller Stakeholder, Quellen für die laufende Finanzierung und Unterstützung durch lokale Regierungen wurden als kritisch für die Nachhaltigkeit von Zuchtprogrammen erkannt. Die Studien dieser Arbeit zeigen, dass dörfliche Zuchtprogramme bei Rindern erfolgreich umgesetzt werden können. Die Tierhalter akzeptierten die Grundsätze einer strikten Selektion männlicher Tiere und waren sehr aktiv bei der Umsetzung der Zuchtprogramme. Die Nachhaltigkeit der hier implementierten Zuchtprogramme hängt vom weiteren Engagement vieler Stakeholder ab, nicht zuletzt der Beamten der lokalen Regierung und auch des Projekt-Teams.

Chapter 1
General introduction

1.1. Importance of livestock in livelihoods

Agriculture, with the livestock sector as a major component, is the main source of livelihoods for the large majority of people in West Africa and remains the main contributor to gross domestic product (GDP) in many countries there (Fall et al., 2016). Livestock keeping is an important socio-economic activity both for household and national economies,(Thébaud et al., 2018). Indeed, a significant proportion of the 377 million of people in this region depends directly or indirectly on livestock value chains for food, as input to crop production, transport, as a source of cash, investment, and storage of wealth, for ritual and social purposes, or an insurance during impending crisis (Molina-Flores et al., 2020; Valerio et al., 2020). In some Sahelian countries, such as Burkina Faso, Mali and Niger, livestock production involves about 60 percent of the populations and contributes between 37 and 82 percent to the agriculture GDP (Molina-Flores et al., 2020). The major animal resources of economic importance include cattle, sheep, goats, pig, and poultry. In 2017, the animal population in West Africa was estimated about 103.44 million of TLU distributed including 74.3 million cattle, 102.95 million sheep, 157.75 million goats 13.68 million pigs, and 559.91 million chicken (FAOSTAT, 2019).

Burkina Faso is primarily an agro-pastoral country in which the agriculture sector (crop and animal production) are the pillars of the economy. The sector contributes globally about 35 percent to GDP, involves about 86 percent of country workforce and constitutes the main source of incomes for the poorest segment of the population. In Burkina Faso, livestock play an important role at micro- and macroeconomic levels. Livestock contributes about 12 to 20% to the GDP and about 35% to the agriculture GDP (FAO, 2019a; The World Bank, 2017). The sector contributes considerably to food and nutrition security; it remains the primary source of cash income for rural households; it serves as a stock of wealth to cope with climatic change and economic shocks in view of its resilience to rebuild or restock quickly after climatic shocks, particularly drought and; it contributes to the intensification of farming activities as it provides for crop-livestock integration through provision of animal traction and manure for soil fertility (The World Bank, 2017). The population of major livestock species is estimated about 14 million goats, 9 million cattle, 9 million sheep, xx million pigs and 44 million chicken. About 87% of cattle are reared in extensive system while 11% and 2% are under semi-intensive and intensive systems respectively (FAO, 2019a).

1.2. Cattle genetic resources

The diversity of African cattle ranges from breeds adapted to the borders of the Sahara Desert in North Africa, to those able to survive in wet tropical lowlands, to breeds that thrive in the vast savannah of southern Africa (Dessie and Mwai, 2019). Currently, 180 breeds of cattle have been recognized in sub-Saharan Africa; 150 breeds of indigenous cattle and recently introduced exotic and commercial composites (Rege et al., 1996; Rege and Tawah, 1999). Phenotypically, native African cattle are mainly constituted by the humped cattle or zebu cattle (Bos indicus), Sanga and Zenga cattle which are ancient crosses of zebu an *Bos Taurus* cattle, and the humpless cattle (*Bos Taurus*) now found nearly exclusively in West Africa (Hanotte et al., 2009; Mwai et al., 2015). Nowadays, European type taurine commercial breeds and their crossbreds are found in almost every part of the continent although their population are relatively low compared to indigenous breeds. Indigenous breeds are well adapted to local environmental conditions such as high temperatures, long periods of drought and vector-born disease that are less suitable to exotic breeds of European origin.

West Africa differs from other regions of Africa by having significant populations of both Zebu-type (*Bos indicus*) and taurine-type (*Bos Taurus*) sub-species of domestic cattle (Molina-Flores et al., 2020). Zebu cattle type was traditionally found in the Sahel and the Sudan agroecological zones while the habitat of the taurine cattle is mainly restricted to the more humid and tsetse-infested Guinean agroecological zone where Zebu does not thrive well due to its susceptibility to trypanososmis disease. Taurine cattle are tolerant to trypanosomosis disease but are small in size and the productivity is lower compared to most zebu-type cattle. Indigenous cattle breeds are kept by farmers in the different agroecological areas for multiple needs including food (meat and meat), cash incomes and socio-cultural uses (Ejlertsen et al., 2013; Ouédraogo et al., 2020b; Rege and Tawah, 1999; Traoré et al., 2017; Yakubu et al., 2019). However, this traditional distribution of indigenous cattle breeds in the regions has changed over time due to changes of environmental and socio-economic contexts. Since the severe droughts of 1970s and 1980s in the region, an important flux of pastoralists with their Zebu from the northern Sahelian regions into the southern Sudanian and Guinea zones has been observed (Boutrais, 2007; Traoré et al., 2015, 2017). Uncontrolled and indiscriminate crossbreeding among local cattle types is thus taking place with the objective of improving the size of taurine cattle and the trypanotolerance of Zebu. This increases the introgression of zebuine blood into to taurine blood (Alvarez et al., 2014; Kassa et al., 2019;

Scheper et al., 2020) and leads to the dilution of trypanotolerance ability and threats the genetic integrity of West African taurine cattle types (Alvarez et al., 2015, 2014; Traoré et al., 2015). In Burkina Faso, evidence of introgression of Zebu into the native Baoulé cattle has been reported (Alvarez et al., 2015, 2014; Soudré et al., 2019).

1.3. Genetic improvement in cattle

Despite being adapted to local environmental and production conditions; local cattle breeds are characterized by their low production performances. To improve the local production to meet the growing demand of the human population for products of animal origin, a common genetic improvement strategy is the introduction of exotic breeds for crossbreeding. The aim of crossbreeding is to combine the productivity of exotic breeds and the adaptability of local ones and to make use of the heterosis effect to improve milk production. Exotic breeds introduced include European taurine type such as Holstein Friesian, Montbéliarde, Brwon Swiss, Tarentaise, Jersey, Normande (Belemsaga et al., 2005; Marshall et al., 2017; Roessler, 2019; Roessler et al., 2019; Umar et al., 2020) and Zebu types from Latin America, mostly Guzerat, Gir and Girolando (Alkoiret et al., 2011; Marshall et al., 2017; Soudré et al., 2018). In general, exotic breeds and crossbreds perform better than local ones and performance increases with the proportion of exotic blood and management conditions (Marshall et al., 2017; Ngono et al., 2018; Saleh et al., 2016). However, the success of crossbreeding is still limited by the lack of strong organizations in which farmers having the same interest would cooperate. Furthermore, exotic, and crossbred animals do not fully express their genetic potential due non-genetic factors such as feed shortage, diseases, and heat stress in severe climatic conditions (Alkoiret et al., 2011; Rahimi et al., 2020).

In addition to crossbreeding, breeding programs have been promoted for local cattle breeds in West Africa. Many of these programs aimed at improvement of productivity but also the resistance to diseases which is an important constraint of cattle production. Since the 1970s breeding programs using various schemes have been implemented to improve meat, milk and trypanotolerance ability of N´Dama cattle in Senegal, Mali and The Gambia (Bosso, 2006; Bosso et al., 2009, 2007; Camara, 2019; Camara et al., 2020). In Burkina Faso, programs aiming to improve milk performance of Fulani Sudanese and Azawak zebus have been reported. Some of these programs stopped at the end of the project duration, and achievement were generally below expectation. Many factors influence the success of breeding programs, including the adequacy of breeding objectives, availability of infrastructures and involvement of stakeholders (Kosgey et al., 2006).

Indeed, many breeding programs failed in developing countries due to lack of involvement of the farmers (Wurzinger et al., 2011).

1.4. Community-based breeding programs

Breeding programs described as community-based cover a range of situations but typically relate to low-input systems with farmers within limited geographical boundaries having a common interest to work together for improvement of their genetic resources (Mueller et al., 2015). Community-based breeding programs (CBBPs) are thus a participatory approach advocated for low-input smallholders farming systems because they take into account the indigenous knowledge of the communities on breeding practices and breeding objectives and also consider the production system holistically and involve the community at every stage, from planning to operation of the breeding program (Gizaw et al., 2013; Mueller et al., 2015; Sölkner et al., 1998; Valle Zarate and Makermann, 2010; Wurzinger et al., 2011). Planning of CBBPs follows the same basic steps and principles as that of conventional breeding programs (FAO, 2010a; Iniguez et al., 1998; Sölkner et al., 2008). These steps include: consideration of enabling environment; understanding the production system and defining the breeding objective; choice of selection criteria and recording; development of genetic evaluation and breeding structure and its organizations; and evaluation of proposed program (Haile et al., 2018, 2011; Mueller et al., 2015). CBBPs have been widely implemented in various livestock species around the world. Among others, Llamas and goats in Bolivia and Mexico, sheep in Ethiopia, pigs in Vietnam, goats in Iran, sheep in Peru, goats in Argentina, goats in Kenya, see Mueller et al., (2015). However, CBBPs of cattle are rare, probably because of small numbers of stock in households, slow and low reproduction, availability of frozen semen and higher effectiveness of artificial insemination. Yet, it may be a valuable option for keepers of local breeds where there is not offer of external breeding stock or services (Mueller et al., 2015).

1.5. Context, aims and objectives of this thesis

In 2016, the Austrian Partnership in High Education and Research for Development funded a research project 120 “Local Cattle Breed of Burkina Faso – Characterization and Sustainable Use (LoCaBreed)”. Implemented in the framework of international cooperation, the project involved the University of Natural Resources and Life Sciences (BOKU), the University of Veterinary Medicine Vienna in Austria and the Norbert Zongo University, the Nazi Boni University and the Environment and Agricultural Research Institute (INERA) in Burkina Faso. The general objective of the project is to contribute to livelihood improvement and a better understanding of Burkina Faso local cattle breeds. Specifically, it aims to: i) strengthen the capabilities of Burkina Faso in animal breeding and genetics for sustainable management of farm animal genetics resources (FAnGR); ii) characterize local cattle breed at phenotypic and genetic levels for improvement taking into account indigenous knowledge; iii) develop tools for easy identification of crossbred animals for sustainable breeding, optimal African animal trypanosomosis (AAT) diagnostic test applicable under field conditions; compare infection status in cattle and tsetse flies; iv) initiate sustainable breeding and conservation programs for Baoulé and Zebu × Baoulé crosses using community-based breeding approach.

This thesis is part of the project; and its global objective is to initiate appropriate breeding programs to improve the local taurine Baoulé cattle and crossbreds (Zebu × Baoulé) in the South West of Burkina Faso using community-based breeding approach.

The specific objectives are to:

1. characterize the local cattle production and identify the breeding objectives

2. implement community based-breeding programs for pure taurine Baoulé and crossbreds (Zebu × Baoulé)

3. use genomic information for the characterization and the management of the breeding populations

4. investigate the history of cattle genetic improvement in West Africa

1.6. Description of study area

Burkina Faso is a landlocked country located in the Sahel in the middle of West Africa. The country covers 274 200 km^2 and about 21.5 million of people live there (INSD, 2020). It has a tropical climate type, subdivided in three climatic zones: the Sahelian zone in the north, the north-Sudanian zone in the center and the south-Sudanian zone in the south. The annual rainfall increases substantially from the Sahelian to the south-Sudanian zones. Overall, the country faces unfriendly agro-ecological conditions with low, irregular precipitation (World Bank, 2019).

This study was carried out in the province of Poni in the South West administrative region of Burkina Faso, located at 10° 19´ N latitude and 3° 10´ W longitude (Figure 1). This area is the original habitat of Baoulé cattle. The area is trypanosomosis challenged (Silbermayr et al., 2013;

Soudré, 2011). The climate is of the Sudanese type with two distinct seasons: a rainy season from June to October and a dry season from November to May. In 2018 the total amount of rainfall was 1399 mm. The annual average minimum temperature was 22.16°C and the annual average maximum was 33.85°C. The lowest monthly average minimum temperature was registered in January (15.76°C) and the highest monthly average maximum in April (36.65°C). In this area, people produce crops and keep livestock and also perform agroforestry. Production systems are mixed crop-livestock, with the Lobi ethnic group concentrating on subsistence crop production and the migrants tending to keep their lifestyle of pastoral livestock production. The cattle population in this region is estimated about 343 000 heads, representing about 4% of the estimated national stock of 9 million (MRA, 2014). Three sites were selected, based on the availability of Baoulé and crossbreds (Baoulé × Zebu) and the willingness of the farmers to participate in the breeding program. The municipality of Bouroum-Bouroum, located at 25 km from Gaoua, the capital of the South West administrative region, is an area inhabited mostly by the Lobi ethnic group, who keep mostly pure Baoulé herds. Loropéni and Kampti municipalities, located about 35 km and 40 km from Gaoua, respectively, are areas with a high share of migrant people, due to the availability of pasture and water sources. Kampti is situated along the border to Côte d'Ivoire. These are the areas identified as potential areas of Baoulé x Zebu crossbred. In Loropeni, the cattle herds included in this study were owned by native people, whereas herdsmen were frequently migrants. In Kampti, the study included herds owned and managed by migrants.

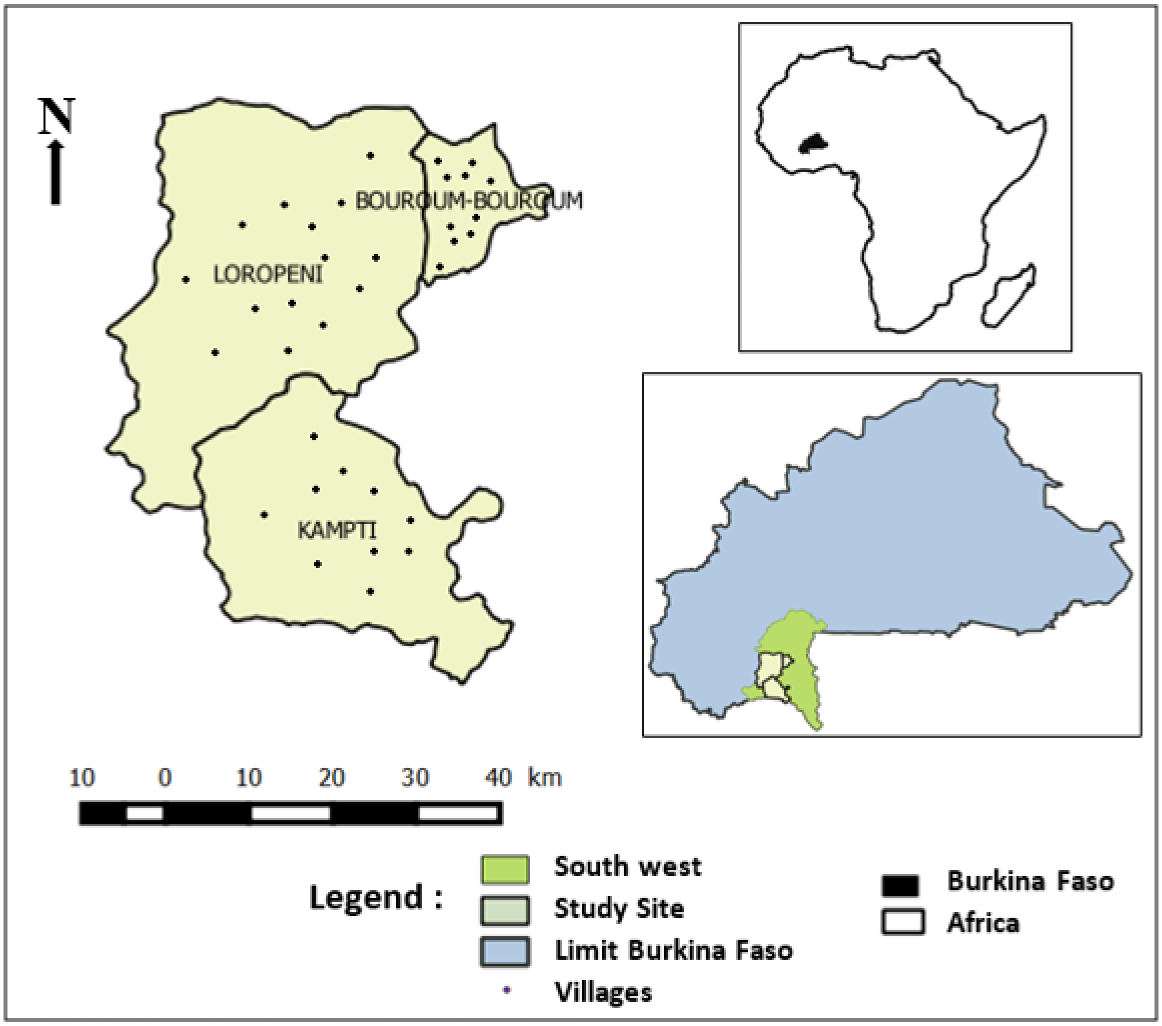

Figure 1.1: Map of Burkina Faso showing the three study areas

The administrative region of South West is delimited in green. The yellow color shows the three communes in which the breeding programs are being implemented. The black dots represent the villages where animals were sampled.

1.7. Outline of chapters

The thesis is structured in 6 chapters. The current chapter (**chapter 1**) explains the context and the justification of this study. It provides a literature review of the existing knowledge about cattle genetic resources and genetic improvement in West Africa and the concept of community-based breeding program and its application to cattle.

Chapters 2 to **4** are focused on the practical implementation of community-based local cattle breeding programs**. Chapter 2** is about breeding objectives and practices in three local cattle production systems in Burkina Faso with implications for the design of breeding programs. **Chapter 3** is about selection of bulls for the implementation of community-based local cattle breeding programs in Burkina Faso. **Chapter 4** is about population structure, inbreeding and admixture in local cattle populations managed by community-based breeding programs in Burkina Faso.

Chapter 5 provides a review of breeding programs for local cattle breeds in West Africa.

Chapter 6 presents a general discussion of the implementation of breeding programs done in this study, pointing out the main findings and their implications.

Chapter 2

Breeding objectives and practices in three local cattle production systems in Burkina Faso with implication for the design of breeding programs

Dominique Ouédraogo[a,b], Albert Soudré[c]*, Salifou Ouédraogo-Koné[b], Bienvenue Lassina Zoma[ab], Bernadette Yougbaré[eb], Negar Khayatzadeh[b], Pamela Burger[d], Gábor Mészáros[b], Amadou Traoré[e], Okeyo Ally Mwai[f], Maria Wurzinger[b], Johann Sölkner[b]

[a]Institut du Développement Rural (IDR), Université Nazi Boni (UNB), BP. 1091, Bobo-Dioulasso, Burkina Faso

[b]Division of Livestock Sciences, Department of Sustainable Agricultural Systems, University of Natural Resources (BOKU), Gregor-Mendel-Str. 33, A-1180, Vienna, Austria.

[c]Unité de Formation et de Recherche en Sciences et Technologies (UFR/ST), Université Norbert Zongo (UNZ), BP 376, Koudougou, Burkina Faso.

[d]Forschungsinstitut für Wildtierkunde und Ökologie, Veterinary medicine University (Vetmeduni) Vienna, Savoyentrasse 1, 1160 Vienna, Austria.

[e]Institut de l'Environnement et de Recherches Agricoles (INERA), BP 8645 Ouagadougou, Burkina Faso.

[f]International Livestock Research Institute (ILRI), PO Box 30709, Nairobi 00100, Kenya.

*Corresponding author:

Tel.: +226 70256935

E-mail address: asoudre@gmail.com

Postal address: B.P. 376 Koudougou, Burkina Faso

Livestock Science 232 (2020) 103910 (https://doi.org/10.1016/j.livesci.2019.103910)

2.1. Abstract

Understanding characteristics of production systems and identification of specific preferred traits related to breeding objectives is a first important step to the successful implementation of any breeding program. This study was conducted in the South West of Burkina Faso, the traditional habitat of trypanotolerant Baoulé cattle, to identify farmers' trait preferences and breeding practices. Following a synthesis of information from stakeholders, a structural questionnaire was designed and administered to 194 heads of households. Cattle herd structure was investigated via herd survey on 101 farms to record breed, age, status, weight and linear body measurements of animals. Own herd ranking method was used in addition to identify the most important criteria for selecting breeding cows. The importance of each criterion was estimated by computing the index of ranking. Regarding breeds and herd mobility, sedentary pure Baoulé, sedentary mixed breed, and transhumant Zebu and crossbred systems were defined. Average cattle herd size was 51.23±55.72 heads and was significantly ($P<0.05$) highest in the transhumant Zebu and crossbred system. Herd structure showed that cows were the most frequent age-sex-class in all the production systems. A high proportion of all farmers reported purposefully selecting their breeding animals but only 36.67% of them in pure Baoulé system select their breeding females. Breeding bulls were selected from young males in the own herd and they were selected significantly ($P<0.05$) later in pure Baoulé system. The majority of transhumant farmers reported castration of not selected males while only 33% of farmers in pure Baoulé system reported that. The most important common criteria for selection among the production systems were adult size for both males and females, including calf growth for females. Production systems were heterogeneous on the other preferred traits. Based on these findings, implementation of breeding programs involving farmers and their specific characteristics and practices can contribute to improve and conserve local cattle breeds in this area. Community-based breeding programs for pure Baoulé and crossbreds aiming to improve body size and trypanotolerance are being implemented.

Key words: Cattle, Trait preference, Breeding, West Africa.

2.2. Introduction

In most developing countries in Sub-Saharan Africa, cattle production is based on indigenous breeds, which are adapted to the local environment but characterized by relatively low productivity and generally perform poorly compared to commercial breeds (Mwai et al., 2015; Renaudeau et al., 2012). Baoulé cattle (*Bos taurus*), locally called Lobi cattle, is an important taurine population located in the South West of Burkina Faso, a region known to be a tsetse challenge (Soudré, 2011; Soudré et al., 2019). This trypanotolerant breed, which is considered rustic, is owned by the Lobi ethnic group. It is kept in small herds and, used for ploughing as well as for several social activities. However, because consecutive droughts in the 1970s and 1980s negatively affected forage and water resources in the Sahelian part of the country, increasingly, transhumant pastoralists moved to settle down with their Zebu cattle in the more humid Southern area. Alongside the settlement, bush clearing for agriculture, implementation of tsetse control programs, and widespread use of trypanocides have been observed (Traoré et al., 2017). Trypanosusceptible Zebu are now frequently mated with local taurine animals to produce larger and trypanotolerant crossbreds, leading to introgression of Zebu genes into taurine breeds. Several investigations reported the absorption and the threat of extinction of West African taurine types of cattle due to the crossing with Zebu (Alvarez et al., 2014; Belemsaga et al., 2005; Soudré et al., 2019; Traoré et al., 2015; Yapi-Gnaoré et al., 1996). The specific case of Baoulé cattle is also documented (Mopaté et al., 2014; Sokouri et al., 2007; Soro et al., 2015; Soudré et al., 2019). Nevertheless, indigenous cattle breeds are disappearing not only because of indiscriminate crossbreeding by individual farmers, but also because of schemes for genetic improvement that were developed without concern for preservation of locally adapted breeds (Belemsaga et al., 2005). Many breeding programs or genetic improvement strategies in developing countries failed due to the lack of involvement of beneficiaries (Duguma, 2010; Mhlanga, 2002). Community-based breeding is recognized to be adapted to low input production systems and this approach requires full participation of farmers in the different steps of implementation (Sölkner et al., 1998; Wurzinger et al., 2011). The implementation of a sustainable community-based breeding program requires a good understanding of production system, selection criteria and breeding goals (Mueller et al., 2015; Ndumu et al., 2008). A breeding objective defines the direction in which the farmer aims to go towards satisfying the demand for specific products and services from the animal (Sölkner et al., 2008). While in conventional market-oriented livestock production systems, breeding objectives can often be directly derived from economic values of traits involved (Goddard, 1998), in traditional systems because the animal has multiples functions determining breeding objectives is more complex. Analysing farmers' preferred trait levels in the animals may provide the breeding objective indirectly (Duguma et al., 2011).

Production systems and traits preferred by farmers for cattle in tropical areas were investigated by several studies. In Central and Eastern Africa, production systems and traits preferred by Ankole cattle keepers in Uganda, Rwanda and Tanzania were documented (Ndumu et al., 2008; Wurzinger et al., 2006). In Eastern Africa, breeding objectives of Sheko cattle keepers, breeding practices and farmers' preferences on indigenous dairy cattle in Ethiopia were investigated (Bayou et al., 2018; Desta et al., 2011; Zewdu et al., 2018). In West Africa, Tano et al. (2003) reported farmers' preferences for cattle traits. More recently, cattle farmers' breeding objectives, practices, traits and breeds preferences were investigated in Gambia, Mali and Nigeria (Ejlertsen et al., 2013; Traoré et al., 2017; Yakubu et al., 2019). Production systems and breeding practices are strongly influenced by farmers' characteristics as well as by the local environment.

This study was set up to investigate the breeding practices, breeding objectives and the implications for designing and implementing appropriate breeding programs for local cattle in the South West of Burkina Faso.

2.3. Materials and methods

2.3.1. Data collection

To achieve a global view on production systems in the area, focus group discussions were carried out in October 2016 to collect information from farmers and government livestock extension services. Three focus groups discussions were held, one per location. Discussions focussed on breeds, breeding and transmission of traits. In open discussion, each participant was encouraged to give his/her point of view about the topic. A questionnaire was designed based on the information from focus groups discussions. The questionnaire collected information on farmers' characteristics, reasons for keeping cattle, herd size, herd composition and structure, reproductive performances, traits preferred for breeding bulls and cows' selection and breeding bulls' management. The questionnaire was pre-tested on 10 farmers to check whether questions were clear and adequate and whether respondents could understand them. The questionnaire was administered individually to the heads of each household and was encouraged that any other family member provides of additional relevant information. The questionnaire was administered in the farmer's native language with the help of translators. Due to the lack of exhaustive lists of farmers keeping cattle in the three sites, classical fully randomized sampling was not possible. Thus, the snow-ball sampling was used (Dossa and Vanvanhossou, 2016). A total of 194 household heads were interviewed from January to July 2017.

Among the farmers surveyed, 101 (56 from Bouroum-Bouroum, 26 from Loropeni and 19 from Kampti) showed interest in taking part in a breeding program. For these farms, baseline herd survey was conducted from April to June 2017. Information on breed, age, status and physiological state and linear body measurements such as height at withers, body length, chest circumference of animals were recorded. The estimated body weight (kg) was recorded using a weigh band measuring chest circumference. Height at withers is the vertical distance from the bottom of the front foot to the highest point of the shoulder between the withers, measured in centimeters. Chest girth is the circumference of the body immediately behind the shoulder blades in a vertical plane, perpendicular to the long axis of the body, also measured in centimeters. Body length is the horizontal distance from the point of the shoulder to the pine bone, measured in centimeters (FAO, 2012).

Due to lack of recording system, animals' age was determined via teeth examination. Permanent teeth eruption, development and wear was use to estimate cattle age (Parish and Karisch, 2013).

Identification of breeding objectives traits was done in a participatory manner (Duguma et al., 2011; Sölkner et al., 1998; Wurzinger et al., 2011). As recommended (Haile et al., 2011; Ndumu et al., 2008), two methods were combined. First, during the household survey, farmers were provided with a list of 10 traits and were asked to tick the traits preferred for the selection of breeding bulls and cows. An option of adding other traits was also provided. Furthermore, they were asked to rank their three most important traits. In addition to the survey, own herd ranking was carried out from June to September 2018. Sixty-seven farms among those involved in the breeding programs were visited individually and households' members were asked to choose their best, second best, third best and worst breeding cows in their herds. Due to the small number in the herds, bulls were excluded from the own herd ranking. A total of 268 female animals were included in the ranking. The reason of ranking and life history of ranked animal (age, number of calvings, number of weaned calves, origin and body condition score) were inquired and recorded.

2.3.2. Data analysis

R version 3.5.2 code and functions were used to describe the data. For survey data, Pearson's Chi-square test was employed to test the independence of categories and to assess the statistical significance. For traits preference, frequencies were computed for the proportion of respondents using particular criteria and the importance of each criterion was estimated by computing the index of ranking. Index= Sum (3×rank1 + 2×rank2+ 1×rank3) for individual trait / Sum (3×rank1 + 2×rank2 +1×rank3) for overall traits (Bayou et al., 2018; Getachew et al., 2010; Zewdu et al., 2018). For quantitative data, means and standard deviation were computed and comparison of means was performed. Shapiro test and Q-Q normality plots were used to examine the distribution of data. For normal distributed data, ANOVA and Tukey-test was used to compare the least square means (LSM); when data were not normally distributed, Kruskal-Wallis test was employed to test the level of significance and ranks were analysed by Wilcoxon pairwise test (Janssen-Tapken, 2009). Means and LSmeans were compared using 0.05 level of significance.

A General Linear Model (GLM) procedure was implemented to analyse body weight of cows, heifers and mature bulls. The statistical model used was: $Y_{ij} = \mu + A_i + B_j + (A\times B)_{ij} + e_{ijk.}$

Where Yij = observed body weight; μ= the overall mean; A_i = the fixed effect of age-sex-class (i=cows, heifers, bulls); B_j= the fixed effect of production system (j= sedentary pure Baoulé system, sedentary mixed breed system, transhumant Zebu and crossbred system); $(A\times B)_{ij}$ = the interaction between age-sex-class and production systems; e_{ijk}= random error (Guangul, 2014).

2.4. Results

2.4.1. Owners' characteristics

The socio-demographic characteristics of cattle owners' and their households in the study area are summarized in Table 1. In addition to the type of the breeds owned, the mobility of the herd was used to define three production systems in the area: sedentary pure Baoulé, sedentary mixed breed, and transhumant Zebu and crossbred systems. In sedentary systems, owners were native people living in Bouroum-Bourom and Loropéni, respectively. In transhumant Zebu and crossbred system, farmers were migrants settled in Kampti and, 77.00% of them practiced seasonal mobility, specifically during the dry season for forage and water exploitation.

The majority of the farmers surveyed were male, their average age was around 50 years (27-88) and most of them were illiterate (all farmers in pure Baoulé system). Average household size ranged from 12.60 to 15.80, they were the largest in the pure Baoulé system. All the farmers (100%) in the sedentary pure Baoulé system and a proportion of 81.08% in the sedentary mixed breed system were of Lobi ethnicity while almost all of the respondents in the transhumant Zebu and crossbred system were Fulani and Mossi. The main source of income was crop in both sedentary systems, while it was livestock in the transhumant one. The average cultivated land size in the sedentary pure Baoulé system was significantly higher than in the other two systems. Maize, sorghum and millet were the main crops. Besides cattle, sheep, goats and poultry were reared in all sites, while pigs were only found in Lobi households. Purchasing animals was the main source of establishing herds in both sedentary pure Baoulé and sedentary mixed breed systems, while almost two thirds of respondents in transhumant Zebu and crossbred system inherited their cattle.

Table 2. 1 : Socio-demographic characteristics of cattle owners' households in the study area

	Production system			
Characteristics	Sedentary pure Baoulé (n=60)	Sedentary mixed breed (n=37)	Transhumance Zebu and crossbred (n=97)	P-value
Ethnic groups (%)				< 0.0001
Lobi	100.00[a]	81.08[b]	0.00	
Djan	0.00	18.92	0.00	
Fulani	0.00	0.00	75.25	
Mossi	0.00	0.00	19.59	
Others	0.00	0.00	5.15	
Education (%)				< 0.0001
Illiteracy	100[a]	78.38[b]	96.91[a]	
Literacy	0.00	21.62	3.09	
Main source of incomes (%)				< 0.0001
Crop	100.00[a]	86.49[b]	13.4[c]	
Livestock	0.00	2.70	78.35	
Trade	0.00	10,81	8.25	
Cattle acquisition (%)				< 0.0001
Heritage	16.67[a]	2.70[a]	68.04[b]	
Gift	3.33	0	2.06	
Purchase	80.00	97.30	25.77	
Others	0.00	0.00	4.12	
Transhumance				< 0.0001
Yes	0.00	8.11	77.32	
No	100.00[a]	91.89[a]	22.68[b]	
Age of Household (Years)				
Mean±SD	56.78±11.42[a]	51.89±10.71[a]	46.90±12.15[b]	*
Size of household (Individuals)				
Mean±SD	15.81±7.82[a]	13.00±6.55[b]	12.58±5.95[b]	*

Chi-square used to test the significance difference and to perform pairwise comparisons for categoricale variables. Kruskall-Wallis test and Wilcoxon pairwise used for continuous variables. Signifance difference between production systems (P<0.05) is indicated by different letters.
SD= Standard Deviation.
*: P<0.05 (Significance difference between the production systems tested by Kruskal-Wallis test and pairwise comparison by Wilcoxon test).

2.4.2. Purpose of keeping cattle

The reasons of keeping cattle according to the respondents are shown in Figure 2. Cash income was the primary purpose for keeping cattle (almost 100% in sedentary mixed breed system), followed by social reasons, saving and, good wealth status. In addition, milk for home consumption was frequently reported by transhumant farmers while respondents from the other two systems did not mention milk. Keeping cattle for milk, saving, wealth status and other reasons were significantly different among the production systems.

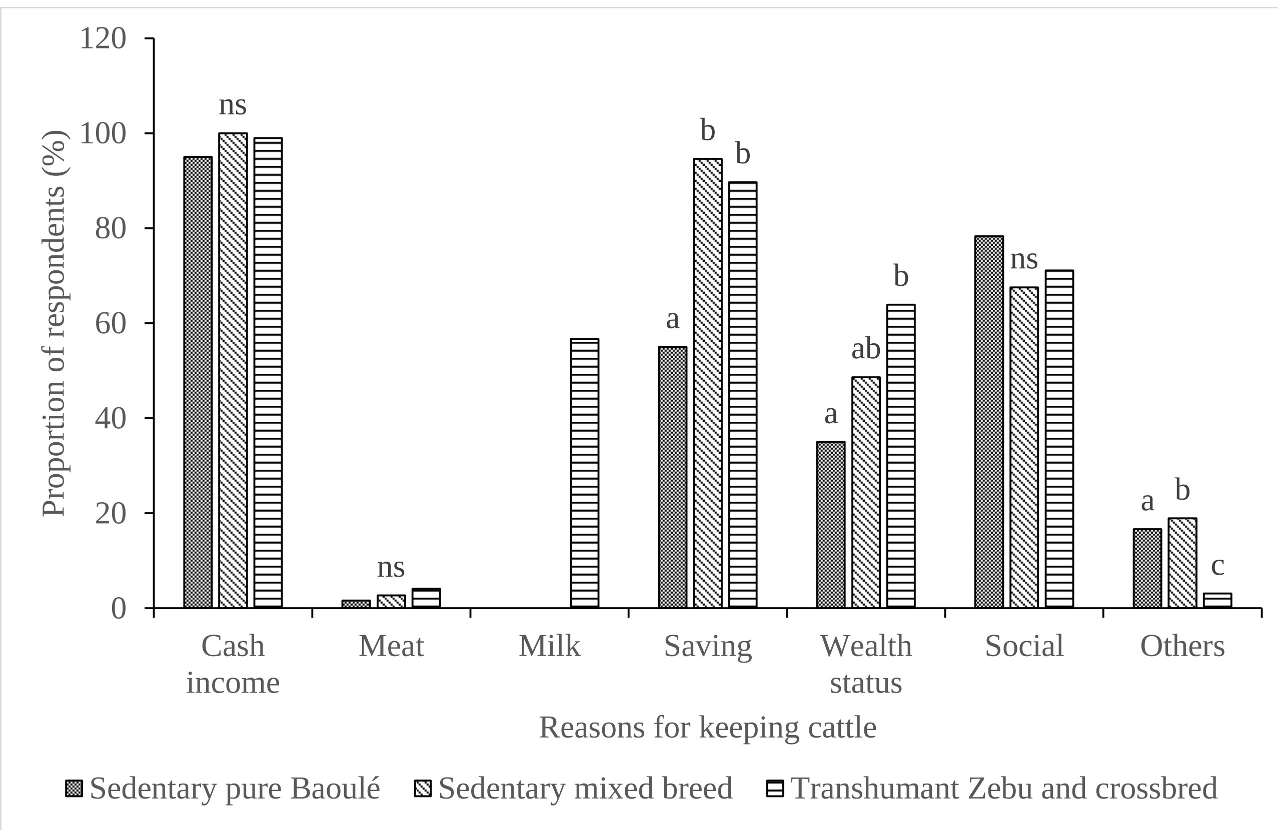

Figure 2. 1: Proportion of households keeping cattle for particular reasons across production systems (More than one response is possible)

Chi-square used to test significance difference and to perform pairwise comparisons. Significance difference (P<0.05) between the production systems is indicated by different letters.

2.4.3. Cattle herd structure

The distribution of livestock species and cattle breeds in surveyed households is presented in Table 2. The overall cattle herd size was 51.23±55.72 heads. It varied from 20.93±16.49 heads in sedentary pure Baoulé to 70.29±64.66 heads in transhumant Zebu and crossbred system. Cattle herd size was significantly higher in transhumant as well as sedentary mixed breed systems than in sedentary pure Baoulé system. The distribution of breeds showed that pure Baoulé, crossbreds and pure Zebu were present in all three areas, but in varying proportions. Very few pure Zebu and crossbreds were found in the sedentary pure Baoulé system and very few pure Baoulé were encountered in the transhumant Zebu and crossbred system.

The herd structure of cattle was described via the distribution of animals in age-sex-classes per production system (Table 3). Cows and heifers were the most important categories in all three production systems. The lowest average number of cows was recorded in the sedentary pure Baoulé system and the highest in the transhumant Zebu and crossbred system. The same trend was observed with heifers. Contrary to other categories there was no significant difference across production systems for bulls and male calves. Average numbers of bulls per herd were in the range of less than two for sedentary pure Baoulé, and five to six in sedentary mixed breed and transhumant Zebu and crossbred systems.

Least square means and standard errors (LSM ± SE) of body weight for different age-sex-classes were reported in Table 4. Adult animals in sedentary mixed breed and transhumant Zebu and crossbred systems are significantly heavier than in pure Baoulé system.

Table 2. 2 : Distribution of livestock species and cattle breed by production system in the study area

	Production System								
	Sedentary pure Baoulé (n=60)			Sedentary mixed breed (n=37)			Transhumant Zebu and crossbred (n=97)		
Species / Breeds	Mean±SD	Median	Range	Mean±SD	Median	Range	Mean	Median	Range
Cattle	20.97±16.49[a]	15	4-92	50.22±50.46[b]	35	7-271	70.29±64.66[c]	50	9-500
Ploughing cattle	3.03±2.26[a]	3	0-10	2.54±2.61[ab]	2	0-10	1.71±1.62[b]	2	0-10
Sheep	11.17±10.23	10	0-40	10.81±10.33	10	100-40	17.10±25.89	10	0-180
Goats	10.00±9.24	9	0-50	7.68±6.21	7	0-20	11.58±10.94	10	0-60
Pigs	7.20±10.72[a]	3	0-60	5.97±9.47[a]	0	0-40	0.74±4.71[b]	0	0-40
Donkeys	0.17±0.64[a]	0	0-3	0.19±0.62[a]	0	0-3	0.01±0.10[b]	0	0-1
Poultry	55.82±46.76[a]	40	0-200	50.89±44.82[a]	30	0-200	67.03±253.55[b]	30	0-2500
Baoulé	20.25±12.54[a]	16	7-68	10.43±22.67[b]	0	0-120	1.36±5.76[c]	0	0-50
Zebu	2.35±7.63[a]	0	0-50	18.08±21.63[b]	12	0-82	54.99±65.24[c]	42	0-500
Crossbred	1.52±7.48[a]	0	0-50	24.51±33.84[b]	15	0-161	15.74±22.33[c]	0	0-100

Significant difference tested by Kruskal-Wallis test and comparison done by Wilcoxon pairwise comparison by production system is indicated with different letter (P<0.05).

SD: Standard Deviation.

Table 2. 3: Distribution of cattle in age-sex-groups by production systems (in number of animals)

Age-sex-classes/PS	Mean	SD	Median	Range	(%)
Sedentary pure Baoulé (n=60)					
Cows	7.75[a]	7.32	6	0-41	31.94
Heifers	4.43[a]	5.48	3	0-35	18.27
Bulls (>3years)	4.30ns	3.33	3	0-13	17.72
Oxen / Castrated	1.12[a]	1.63	0	0-6	4.60
Immature bulls (≤3years)	2.40[a]	3.35	1	0-22	9.89
Male calves	1.93[a]	2.59	1	0-18	7.97
Female calves	2.33[a]	3.11	1,5	0-17	9.62
Sedentary mixed breed (n=37)					
Cows	17.24[b]	15.28	12	0-77	32.08
Heifers	11.11[b]	13.96	7	0-75	20.63
Bulls (>3years)	3.51ns	3.31	2	0-13	6.53
Oxen / Castrated	2.51[b]	3.09	2	0-13	4.57
Immature bulls (≤3years)	6.97[b]	7.23	5	0-35	12.97
Male calves	6.43[b]	6.27	4	0-34	12.04
Female calves	6.05[b]	6.53	4	0-35	11.15
Transhumance Zebu and crossbred (n=97)					
Cows	23.60[c]	25.44	16	4-200	32.87
Heifers	17.47[c]	17.62	15	2-150	24.27
Bulls (>3years)	3.51ns	3.40	2	0-20	4.90
Oxen / Castrated	1.43[a]	3.72	0	0-33	1.99
Immature bulls (≤3years)	10.69[c]	8.79	8	1-60	14.86
Male calves	7.49[b]	6.02	6	0-35	10.42
Female calves	7.70[b]	6.31	7	0-40	10.70

PS : Production System, SD : Standard Deviation

Significant difference tested by Kruskal-Wallis test and comparison done by Wilcoxon pairwise comparison between means of same Age-sex-Class by production system is indicated with different letters ($P<0.05$)

Table 2. 4: Least squares means and standard error of estimated body weight (Kg) at different sex-age-classes across the production systems

	Production system									
	Sedentary pure Baoulé			Sedentary mixed breed			Transhumance Zebu and crossbred			
Age-sex-classes	n	LSM	SE	n	LSM	SE	n	LSM	SE	Sig.
Cows	313	183.00[a]	2.10	167	218.00[b]	2.87	211	248.00[c]	2.56	*
Heifers	81	163.00[a]	4.13	64	187.00[ab]	4.64	51	220.00[b]	5.20	*
Mature males	77	200.00[a]	4.23	28	231.00[a]	12.17	10	315.00[b]	11.75	*

n= Number of animals, LSM= Least Square Means, SE= Standard Error, *: P<0,05 (Tukey test).

2.4.4. Reproduction and mating management

The majority of respondents had their own bulls, serving their own and neighbours' herds in uncontrolled mating (Table 5). Bulls' service and bulls' possession were not significantly different among the production systems. Bulls were mainly kept for mating but 28% of respondents in sedentary pure Baoulé reported use of their bulls both for mating and ploughing. Young bulls from the own herd constituted the main source of mating bulls' replacement in all systems investigated. Mating bulls were conscientiously selected by all farmers in transhumant Zebu and crossbred system, whereas only 65% of farmers in sedentary pure Baoulé selected bulls. The proportion was even lower for cow selection in the pure Baoulé system, namely, 36.67%. Breeding bulls were selected significantly later in pure Baoulé system than in the other systems. However, no significant difference was found among the production systems for the duration of bulls' use. The majority of farmers in transhumant Zebu and crossbred system reported to practice castration of unwanted males, while only 33% of farmers in pure Baoulé system castrated males. The main reasons of castration were to control mating, to enhance docility and to avoid fighting. The practice of castration and reasons for castration among the production systems varied significantly. Few respondents in sedentary pure Baoulé system were aware of artificial insemination, in the other two systems more respondents knew of this practice.

Table 2. 5: Breeding bulls' selection, ownership and management across the production systems

	Production system			
Mating Practice	Sedentary pure Baoulé	Sedentary mixed breed	Transhumance Zebu and crossbred	P-value
Own Bulls (%)				0.10
Yes	95.00	97.30	100.00	
No	5.00	2.70	0.00	
Bulls service (%)				0.56
Own herd	3.51	2.78	1.03	
Own and neighbour herd	96.49	97.22	98.97	
Keeping bull purpose (%)				< 0.0001
Mating	68.42[a]	100.00[b]	98.97[b]	
Socio-cultural	1.75	0.00	0.00	
Fattening	1.75	0.00	0.00	
Mating and ploughing	28.07	0.00	1.03	
Source of replacement bulls (%)				0.34
Young from own herd	96.67	97.30	100.00	

Purchased	1.67	2.70	0.00	
Others	1.67	0.00	0.00	
Selection of best cows (%)				< 0.0001
Yes	36.67[a]	59.46[ab]	77.32[b]	
No	63.33	40.54	22.68	
Selection of best bulls (%)				< 0.0001
Yes	65.00[a]	97.30[b]	100.00[b]	
No	35.00	2.70	0.00	
Castration practice (%)				< 0.0001
Yes	33.33[a]	64.86[b]	71.13[b]	
No	66.67	35.14	28.87	
Reasons of castration (%)				< 0.0001
Mating control	50.00[a]	26.09[b]	44.93[b]	
Fattening	10.00	0.00	1.45	
Better temperament	40.00	52.17	8.70	
Avoid fighting	0.00	21.74	44.93	
Information about Artificial Insemination (%)				< 0.0001
Yes	6.67[a]	16.22[a]	44.33[b]	
No	93.33	83.78	55.67	
Age of selection of males (Years)				
Mean±SD	3.13±1.26[a]	2.83±0.51[ab]	2.72±0.71[b]	*
Duration of breeding bulls use (Years)				
Mean±SD	7.38±3.81	5.92±1.59	6.46±2.09	ns
Age of castration of undesired bulls (Years)				
Mean±SD	3.74±0.87[a]	3.00±0.51[b]	3.20±0.63[b]	*

Chi-square used to test the significance difference and to perform pairwise comparisons. Significance difference between the production systems is indicated by different letters ($P<0.05$). *: $P<0.05$ (Significance difference between the production systems tested by Kruskal-Wallis test and pairwise comparison by Wilcoxon test)

2.4.5. Selection criteria and breeding practices

Female: The relative importance for the criteria of the selection of breeding females across production systems, applying an index, is shown in Table 6. There was a high variability of criteria and their importance across production systems and among employed methods. The survey revealed that adult size was the most important criterion for female selection. Calf growth, milk yield and udder state were ranked after adult size, depending on the production system.

The phenotypic ranking of cows from own herd was more homogenous than compared to the survey. The most important criteria for considering cows' quality were fertility (frequency of calvings) for pure Baoulé system with an index of 0.67 and milk yield, for sedentary mixed breed system as well as for transhumant Zebu and crossbred system. Furthermore, adult size (0.16) and docility (0.12) were considered relevant by pure Baoulé owners.

Male: Criteria for the selection of breeding males and their importance are presented in Table 7. Like for breeding cows, adult size was the most preferred criterion in the three production systems. However, the three production systems were heterogeneous regarding the other important criteria. Docility was second most important in pure Baoulé system while growth and dam of the bull featured second in sedentary mixed breed and transhumant Zebu and crossbred systems, respectively.

Table 2. 6: Table 2.6. Index of breeding cows' selection criteria across the production systems in the Southwestern of Burkina Faso

	Production system											
	Sedentary pure Baoulé				Sedentary mixed breed				Transhumance Zebu and crossbred			
Criteria	Rank1	Rank2	Rank3	Index	Rank1	Rank2	Rank3	Index	Rank1	Rank2	Rank3	Index
Survey												
Size	8	7	2	**0.400**	13	2	2	**0.490**	26	8	4	**0.290**
Coat color	1	0	0	0.030	-	-	-	-	-	-	-	-
Horns	-	-	-	-	-	-	-	-	-	-	-	-
Calves Growth	3	2	2	**0.150**	3	2	2	**0.160**	0	15	6	**0.100**
Calves Survival	1	3	0	0.090	1	3	0	**0.100**	3	3	5	0.060
Frequent calvings	3	0	1	0.100	0	4	0	0.090	4	0	0	0.030
Milk yield	-	-	-	-	1	0	0	0.030	21	13	4	**0.270**
Sexual precocity	-	-	-	-	-	-	-	-	1	1	1	0.010
Mothering	3	3	0	**0.150**	0	4	1	**0.100**	1	1	6	0.030
Udder	0	1	0	0.020	1	0	0	0.030	18	2	1	**0.170**
Other	2	0	0	0.060	-	-	-	-	2	0	2	0.020
Own herd ranking												
Size	6	5	6	**0.160**	0	0	1	0.010	2	3	1	**0.110**
Milk yield	1	1	2	0.030	10	12	10	**0.890**	15	16	18	**0.830**
Fertility	24	24	19	**0.670**	1	0	0	0.040	2	0	0	0.050
Docility	3	5	7	**0.120**	0	0	1	0.010	-	-	-	-
Other	1	0	1	0.020	1	0	0	0.040	-	-	-	-

The highest index value means the highest importance.

Index= Sum of (3 × rank1 + 2 rank2 1 × rank3) for individual trait / Sum (3 × rank1 + 2 × rank2 +1 × rank3) for all traits

Table 2. 7: Index of breeding bulls' selection criteria across the production systems in the Southwestern of Burkina Faso

	Production system											
	Sedentary pure Baoulé				Sedentary mixed breed				Transhumance Zebu and crossbred			
Criteria	Rank1	Rank2	Rank3	Index	Rank1	Rank2	Rank3	Index	Rank1	Rank2	Rank3	Index
Size	28	9	0	**0.520**	31	1	1	**0.540**	52	22	11	**0.400**
Coat Color	0	3	3	0.050	-	-	-	-	2	1	2	0.020
Horns	0	0	1	0.005	0	0	1	0.005	0	0	1	0.002
Growth	1	10	2	**0.130**	1	18	4	**0.240**	9	25	27	**0.200**
Docility	4	7	8	**0.170**	0	2	3	0.040	3	9	7	0.060
Libido	0	2	1	0.030	0	0	1	0.005	0	1	0	0.004
Dam	1	3	0	0.050	1	10	3	**0.150**	33	22	9	**0.290**
Fattening ability	0	1	1	0.010	1	0	0	0.020	0	-	-	-
Sexual precocity	-	-	-	-	-	-	-	-	0	1	0	0.004
Adaptability	1	2	0	0.030	0	0	1	0.005	1	0	0	0.006
Other	1	0	0	0.010	-	-	-	-	2	0	1	0.013

The highest index value means the highest importance.

Index= Sum of (3 × rank1 + 2 rank2 1 × rank3) for individual trait / Sum (3 × rank1 + 2 × rank2 +1 × rank3) for all traits

2.5. Discussion

2.5.1. Herd size, structure, and ownership

Lobi is the dominant ethnic group in the South West of Burkina Faso. The increased proportion of Fulani and Mossi reflects the internal migration of people towards the southern and western parts of the country consecutive to the recurrent drought since 1970s, and resulting search for grazing and crop lands (Henry et al., 2004; Paré et al., 2008). In our study, almost exclusively, men were heads of households congruent with in similar studies conducted in West Africa (Ejlertsen et al., 2013; Traoré et al., 2017; Yakubu et al., 2019). Furthermore, the majority of sedentary people depended primarily on crop production for their livelihood and most of transhumant people had livestock as primary source of income. This fact attests the diversification and the integration of crop and livestock activities in the area and is consistent with the findings of Roessler (2019) in the peri urban and urban areas of Ouagadougou in Burkina Faso. Diversification and integration of crop and livestock are usually reported as a strategy for African farmers to adapt to the global socio-economic and environmental changes (Ayantunde et al., 2014; Zampaligré et al., 2014). This integration aims to capture the advantages of each activity through the use of the animals for ploughing, the use of their manure for crop field fertilization and the value maximization of crop residues as food (Dossa and Vanvanhossou, 2016). However, contrary to rural areas, animals are not used for the preparation of crop fields in peri urban and urban areas (Roessler, 2019).

The observed large herd size in transhumant Zebu and crossbred production system might be explained by the high proportion of Fulani farmers in this group who usually keep cattle in large numbers, subdivided in several herds. The large size of Fulani cattle herds compared to other ethnic groups in West Africa has already been reported (Ayantunde et al., 2007; Houessou et al., 2019). The high proportion of Baoulé cattle in sedentary pure Baoulé system attests the attachment of local people in the South West of Burkina Faso to their traditional breed due to the socio-economic roles of this breed for them (Mopaté et al., 2014). According to Dossa and Vanvanhossou (2016) the attachment of local people to their indigenous breed is favourable for its conservation. The high proportions of crossbreds and Zebu in the sedentary mixed breed system may be explained by the interest of some native people for these genotypes due to their high growth performance, larger size and consequently higher market value. Similar observation was reported with the Lagune taurine cattle farmers in Southern Benin (Ahozonlin et al., 2019). The relative superiority of adult body weight in sedentary mixed breed and transhumant Zebu and crossbred systems, compared to sedentary pure Baoulé system moreover confirmed this fact. The findings of a previous study in the same area, reporting systematic castration of other breeds males kept with Baoulé cattle to avoid crossbreeding (Mopaté et al., 2014) are not confirmed by the present study. Our findings attested the intent of crossbreeding by some farmers with traditional Baoulé cattle, to increase body size and perceived productivity as already mentioned by (Traoré et al., 2015). Concordantly, Ahozonlin et al. (2019) reported that crossbreeding and replacement of Lagune cattle with Zebu in Southern Benin are not uncontrolled/indiscriminate, but purposively done by Lagune cattle farmers, irrespective of their geographic positions, to achieve their production objectives. In West African extensive cattle production systems, uncontrolled crossbreeding can lead to the introgression of Zebu genes in the small cattle population, which represents a threat for cattle genetic integrity (Dossa and Vanvanhossou, 2016; Ndiaye et al., 2015). Some investigations reported the existence of Zebu gene introgression into the taurine cattle of South Western Africa and the possible dilution of their trypanotolerance due to unsupervised crossbreeding (Alvarez et al., 2015, 2014; Soudré et al., 2019; Traoré et al., 2015). Furthermore, the increasing importance of Zebu in the study area could lead Baoulé cattle to be endangered in the short term. Thus, suitable management is required for the sustainable use of local breeds in the region. In this sense, Traoré et al. (2015) suggested the implementation of conservation and selection strategies aiming at the increase of the productivity of native West African taurine cattle breeds while maintaining trypanotolerance. In the South West of Burkina Faso, breeding strategies must include the specificity of the three production systems in terms of breeds preferences. Separate breeding programs are being up to conserve and improve the productivity of pure Baoulé and also to improve the trypanotelance of crossbreds and Zebu.

2.5.2. Production objectives

The diverse reasons of keeping animals in this study confirm the multifunctionality of livestock in the South West of Burkina Faso. Keeping animals for cash income, saving, wealth and social reasons was reported by similar studies on small ruminants and cattle (Duguma, 2010; Guangul, 2014). Our results are comparable to the findings of similar studies in West Africa but differ in the order of importance (Ejlertsen et al., 2013; Traoré et al., 2017). Domestic milk consumption, highly reported in transhumant system, might be explained by the ability of Zebu and crossbreds to produce milk compared to pure Baoulé, thereby attesting the influence of breed on production objectives. The high importance of social reasons observed in sedentary groups confirms that keeping Baoulé cattle is more about meeting on sociocultural and economic needs (Mopaté, 2015). In the same sense, Soro et al. (2015) reported that in the "Pays Lobi" in Cote d'Ivoire, Baoulé cattle are primarily reared for ritual ceremonies, gifts and as security against the vicissitudes of life.

The variability of production objectives among the production systems is in agreement with the findings of Janssen-Tapken (2009) in Eastern Africa. This variability opens the perspectives of creating specialized breeds and the specialization of cattle production in the South West of Burkina Faso. Baoulé cattle known for low milk yield could be improved and oriented to beef production. Kinkpé et al. (2019) in economic analysis in Benin, showed that although Zebu cattle are heavier than taurine, taurine cattle attract higher prices than Zebu per kilogram live weight. In the other hand, Zebu and crossbreds due to their relative superiority in milk yield could be improved as double purpose breeds. Improvement and specialization of cattle breeds and thus production is in farmers' interest to earn higher cash income and thereby improve their livelihoods. Indeed, in Fulani households, milk is more used for home consumption, but excess is sold at local markets, which is the main source of income for women who are more involved in milking (Hampshire, 2006).

2.5.3. Selection criteria and breeding practices

In the South West of Burkina Faso, the traits preferences for cattle reflect the multiple purposes of production objectives. Selection criteria related to productive traits such as adult size, growth performance, fertility and milk yield are of high importance for farmers when selecting breeding animals with some variability across production systems. In all the production systems, adult size for both breeding cows and bulls, fertility and calves' growth of females, and young bulls' growth performances were highly ranked, indicating homogeneous preference (Duguma et al., 2011). High utility values for cattle body size were reported in Eastern, Central and Western Africa (Bayou et al., 2018; Ejlertsen et al., 2013; Kassie et al., 2009; Ouma et al., 2007; Traoré et al., 2017; Yakubu et al., 2019; Zander and Drucker, 2008). Large adult size is dependent on early growth performance hence the preference of young males with good growth performance. Similar findings were reported in Gambia where growth rate was ranked as the second most important trait for farmers (Ejlertsen et al., 2013). In Ethiopia, slow growing animals are usually culled or castrated at an early age to prevent them from mating (Desta et al. 2011). Selecting cattle for large adult size aims to fulfill the objective of earning cash income. In the South West of Burkina Faso, the cattle marketing system is based on selling live animals; larger animals have better market value. Several investigations reported the influence of cattle attributes such as breed, size and apparent health status on buyers' choices (Kassie et al., 2009; Kinkpé et al., 2019). Besides, fertility is an important trait in low input extensive systems (Desta et al., 2011; Ndumu et al., 2008; Ouma et al., 2007; Traoré et al., 2017). Frequency of calvings and calves´ survival are key factors to increase herd size, which in turn is the source of income, prestige, and wealth, attesting the importance of fertility for farmers in the study area.

Production systems were however heterogeneous for the preference of some traits such as milk yield, docility and pedigree. Sedentary pure Baoulé farmers highly ranked docility as preferred traits for the selection of breeding male and female. Docility is highly ranked in this study compared to N'Dama and Fulani Zebu keepers in Mali and indigenous dairy cattle keepers in the Gojjam zone in Ethiopia (Traoré et al., 2017; Zewdu et al., 2018). Sedentary people are more involved in crop production and docility is a key trait for the selection of ploughing animals.

In this study milk yield is considered as daily production. Cows are thus selected to meet the interest of milk production in sedentary mixed breed and transhumant Zebu and crossbred systems, in which herders and owners are Fulani, thus confirming that only the Fulani ethnic group in the area is interested in milk. High preference of females for milk was documented for smallholder farmers who keep cattle primarily for milk production to feed their family and to earn additional income (Desta et al., 2011; Kassie et al., 2009). In addition, cows with high milk production have better fed calves that will have better pre-and post-weaning survival rates, will grow better and, probably, attain better adult size; besides, they reach puberty earlier thus also mate sooner(Zewdu et al., 2006). Furthermore, the udder is reported as additional selection criteria of breeding cows. In small dairy farming systems, udder shape and teat size and emplacement were ranked highly by local cattle farmers in Ethiopia (Tadesse et al., 2005; Zewdu et al., 2018). In the South West of Burkina Faso, farmers cared more about udder health and udder damage. Various characteristics of bulls' dam, including milk yield, were strongly integrated in the selection of breeding bulls in the sedentary mixed breed and transhumant Zebu and crossbred systems. The sire of a young bull was often not known because of uncontrolled mating. Use of dam information for selection of breeding bulls in local cattle production systems was already reported (Ayantunde et al., 2007; Köhler-Rollefson, 2000; Wurzinger et al., 2006).

The two methods employed to investigate the selection criteria were heterogeneous in terms of relative importance of traits, as observed in previous similar studies (Duguma, 2010; Guangul, 2014). In both cases, farmers tended to favor animals based on productive and reproductive traits such as adult size, milk yield, calves' growth and frequency of calving. In own herd ranking farmers concentrated on fewer traits. Both methods can be used to capture breeding objective traits in low input cattle production systems but the heterogeneous outcome stresses again the importance of combining participatory methods (Haile et al., 2011; Ndumu et al., 2008).

Overall, the main goal traits in the South West of Burkina Faso were related to productivity. Our results confirm the findings of previous similar studies attesting that in indigenous cattle production systems, productive traits are ranked higher than adaptive traits such as disease resistance (Wurzinger et al., 2006). The preference of bigger animals was obvious for all production systems. While this is not necessarily linked to a higher productivity of the system, particularly when feed availability is constrained, selection of fast growing young bulls in the framework of a community-based breeding program seems advantageous because growth is relatively easy to measure and highly heritable. Bigger animals at the stage of selection most likely suffered less from diseases than smaller ones. Indeed, traits to be selected must represent the breeding goal, should be easy to measure, heritable and not too many (Sölkner et al., 1998).

Contrary to this study, and a similar one by Traoré et al. (2017), Tano et al. (2003) found that disease resistance was among the most important traits, while body size was among the traits ranked lowest in West African cattle. Health traits are important but difficult to breed for in low input systems with little pedigree recording (Zewdu et al., 2006). Criteria related to morphology traits such as coat colors and horns shape were ranked low in this study demonstrating their insignificance for farmers compared to what was reported by similar studies in Ethiopia with Sheko cattle keepers and in Central Africa with Ankole cattle keepers (Bayou et al., 2018; Ndumu et al., 2008; Wurzinger et al., 2006). These traits related to the beauty of animals may not be considered in community-based breeding programs with the communities involved.

2.5.4. Reproduction and mating management

The high proportion of female animals in the herds corresponds with findings in similar systems (Dossa and Vanvanhossou, 2016; Tadesse et al., 2005). In extensive production systems, females are also kept to produce offspring to reach the objectives of higher prestige, more security and more wealth. The ratio of potential breeding bulls to potential breeding cows observed in this study is lower than in other findings but still higher than recommended values for traditional herds, thus indicating an excess of bulls (Dossa and Vanvanhossou, 2016; Tadesse et al., 2005). The proportion of young bulls (0-3 years) was lower than that of young females in all the production systems indicating selective disposal of young bulls for sale for cash needs.

Despite a current development project by the Ministry of Agriculture, promoting artificial insemination with Holstein Friesian or Montbéliarde cattle to improve milk productivity in the area, natural service with local bulls was almost exclusively used in the study area. On national level, the public artificial insemination service promoted by the Ministry of Livestock Resources is more used by modern cattle breeders (Roessler, 2019). This technology is still not available routinely for rural farmers and its success remains low in extensive systems. Pregnancy rates of 24.2% and 10% were reported respectively for Zebu “Azawak” and “Gourounsi” taurine cattle by Zongo et al. (2001) while Blagna et al. (2017) reported 48.8% in cascades’ region in western Burkina Faso.

Young bulls from the own herd was the main source of breeding bulls and bulls were used for relatively long times, which is in agreement with findings in a comparable study (Ayantunde et al., 2007). Bulls were however, selected later and use longer in our study area than in the peri urban and urban farming system in Ouagadougou (Roessler, 2019). Zewdu et al. (2018) also, found in the East Gojjam Zone in Ethiopia, a high share of farmers obtaining their replacement bulls from neighbours/relatives. Both practices, replacement from within herd and long use of breeding bulls, make the system highly susceptible to inbreeding depression. Yet, the open common grazing system in the area reduces mating of closely related animals. Castrating male animals not suitable for breeding is an important mechanism for maintaining or improving desired qualities (Köhler-Rollefson, 2000). In this study, the reasons for castration were heterogeneous among the production systems but close to the findings of comparable studies (Zewdu et al., 2018). Fulani people castrated more for mating control and the preferential sale of castrated animals and undesirable bulls explained the low number of oxen in their herds. In contrast, for sedentary people who are more oriented in crop production, temperament was the main goal of castration and the high proportion of castrated animals they owned reflects the use of animals for ploughing.

The traditional management practice of castration is positive considering the implementation of a breeding program. For a selection program targeting bulls, sale or castration of not selected bulls are options to avoid undesirable mating. In the sedentary pure Baoulé system, bulls not selected for mating could be used for ploughing.

2.6. Conclusion

This study highlighted herd characteristics, production objectives and traits preferred in three local cattle production systems in the South West of Burkina Faso. The heterogeneity of production objectives and, the difference in breeds preferences through the proportion of the three genotypes (Baoulé, Zebu and crossbreds) showed the distinctness of the different social groups. While need of income is common, local sedentary people show high preference for Baoulé cattle for its social role while crossbreds and Zebu are preferred for market value. Breeding animals are selected to reach the heterogeneous purposes among the production systems. The findings of this study confirm the necessity and urgency to promote suitable breeding programs for local cattle breeds in the South West of Burkina Faso. Implementation of breeding programs, however, should take into account the multifunctional roles of cattle and the specificities of groups. Community-based breeding programs, closely involving groups of farmers, allow for that variability. Distinct breeding programs, targeting the improvement of body size and trypanotolerance, are being implemented in the three production systems, based on results of this study. Their goals are to improve farmers' livelihoods and to contribute to the suitable conservation of animals' genetic resources.

2.7. Acknowledgements

The financial support of the Austrian Partnership Program for High Education and Research (APPEAR) is gratefully acknowledged. We are also thankful to the livestock keepers of Bouroum-Bouroum, Loropéni and Kampti for their availability and willingness to participate in our survey and to the government extension workers for the facilitation.

Chapter 3

Selection of bulls for the implementation of community-based local cattle breeding programs in Burkina Faso

Dominique Ouédraogo[1,3], Albert Soudré[2*], Salifou Ouédraogo-Koné[1], Bernadette Yougbaré[3,5], Bienvenue Lassina Zoma[1,3], Arnaud Stéphane R. Tapsoba[5], Gábor Mészáros[3], Pamela Burger[4], Negar Khayatzadeh[3], Maria Wurzinger[3], Amadou Traoré[5], Ally Mwai Okeyo[6], Johann Sölkner[3]

[1]Université Nazi Boni, Institut du Développement Rural, BP 1091, Bobo Dioulasso, Burkina Faso

[2]Université Norbert Zongo, Unité de Formation et de Recherches en Sciences et Technologie (UFR/ST), BP 376 Koudougou, Burkina Faso

[3]University of Natural Resources and Life Sciences, Division of Livestock Sciences, Department of Sustainable Agricultural Systems, Gregor Mendel Str. 33, 1180 Vienna, Austria

[4]University of Veterinary Medicine of Vienna, Forschungsinstitut für Wildtierkunde und Ökologie, Savoyenstraße 1, 1160 Vienna, Austria.

[5]Institut de l'Environnement et de Recherches Agricoles, Laboratoire de Biologie et Santé Animales, 04 BP 8645 Ouagadougou 04 Burkina Faso

[6]International Livestock Research Institute (ILRI), PO Box 30709, Nairobi 00100, Kenya.

[*]Corresponding author: - Albert Soudré
Address: - Unité de Formation et de Recherches en Sciences et Technologies (UFR/ST), Université Norbert Zongo (UNZ), BP 376 Koudougou, Burkina Faso
E-mail: asoudre@gmail.com Tel: (+226) 70256935

Bulletin of Animal Health and Production in Africa 68, 103-111

3.1. Abstract

Community-based breeding programs (CBBP) are being implemented in the South-West of Burkina Faso. CBBP are participatory programs that involve all local stakeholders in all steps, from designing and planning of the breeding program, all the way to the selection of the breeding stock. The breeding programs are being implemented in three sites Bouroum-Bouroum, Loropéni and Kampti. Cattle genotypes used in the program were pure Lobi (Baoulé) cattle in Bouroum-Bouroum and Lobi x Zebu crossbreds in the other two. The programs aimed to meet the main interest of farmers to have bigger animals which are tolerant to trypanosomosis. This study aimed to select the best young males in participatory manner to use as sirs in the three programs. In the first round of selection, body weight of young bulls, aged 3 to 5 years, were recorded twice, at an interval of 6 months. The project team grouped bulls into three groups (top, medium, inferior) based on an index combining current body weight and growth. Selection committees consisting of male and female cattle owners made their choice of best young bulls based on this information and their own criteria. Of the 10 best bulls selected by the committees 5 were from the top group based on preliminary grouping of the project team. Decision was taken by the farmers to castrate or sell out the non-selected bulls, to avoid undesired mating. Joint use of bulls and bull exchange are still being negotiated by farmers, as it is not a customary practice in the region. Farmers were open and appreciated the concept of joint selection of best young bulls for the community very much. They understood that CBBP are long term and committed their efforts and participation.

Key words: breeding bull, selection, body size, trypanotolerance

3.2. Introduction

In West Africa, cattle are one of the most important ruminant species reared in different production systems, providing different products and services (FAO, 2016). The cattle population is mainly constituted of indigenous humped Zebu and humpless taurine animals. In general, the Sahelian regions constitute the traditional habitat of Zebu cattle while taurine cattle are kept mostly in the Southern tsetse-infested Sudano-Guinea area, due to their tolerance to trypanosomosis (Soudré et al., 2013). These indigenous breeds are recognized to be adapted to the local environment characterized by feed shortage and the persistence of endemic diseases. They equally exhibit a high degree of hardiness across a wide range of temperatures and are tolerant and resilient to diseases (Santoze and Gicheha, 2019). Yet, the productivity per head of these indigenous breeds is very low. Due to the low productivity, keepers of African livestock will struggle to meet the demand of increasing population which is expected to reach 2.5 billion by 2050 (FAO, 2019b).

One of the reasons for the low productivity of indigenous cattle is the lack of suitable genetic improvement strategies in most of the West African countries. Until recently, cattle improvement any country often consisted of importation of semen of exotic breeds for crossbreeding in dairy production. Furthermore, crossbreeding local with Zebu was done to increase body size of the local taurine population. Indeed, the interest of the farmers to increase the size of their taurine cattle has led to an increasing use of Sahelian Zebu for reproduction in both the transitional Sudan-Sahel area and the Southern Sudano-Guinea area (Traoré et al., 2015). This crossbreeding is increasing with the recent migration of Sahelian nomadic people with their Zebu cattle across the different agro-climatic zones of West Africa and their settlement in Southern zones traditionally known to be hostile for Zebu cattle (Traoré et al., 2015). However, this unsupervised crossbreeding leads to introgression of Zebu into West African taurine (Alvarez et al., 2014; Soudré et al., 2019) and the possible dilution of their trypanotolerant ability (Alvarez et al., 2015; Traoré et al., 2015). Several investigations have identified uncontrolled crossbreeding, uncontrolled mating, lack of genetic evaluation and transhumance as threats to the genetic integrity of African indigenous breeds (Mwai et al., 2015). The case of Baoulé cattle (called Lobi locally) has been reported and ways of promoting breeding programs suitable to its in-situ conservation have been suggested (Mopaté, 2015; Sokouri et al., 2007; Soro et al., 2015). The best way to conserve a local breed is to increase the interest of farmers in it. The implementation of conservation and selection strategies aiming at the increase of the productivity of native West African taurine breeds while avoiding loss of trypanotolerance is highly advisable (Traoré et al., 2015).

The aim of this study was to select the best young bulls in a participatory manner to be used as sires in three community-based breeding programmes in Burkina Faso, in order to reach the objectives of farmers to have bigger animals which are tolerant to trypanosomosis.

3.3. Materials and methods

3.3.1. Identification of animals and recording process

The implementation of breeding program requires the identification and the recording of animals´performances. In this study, animals were identified with ears tags. Baseline data was collected on all the animals and pedigree information was recorded when available. Young bulls from 3 to 5 years of age were targeted as potential candidates for the selection. Age was determined by examination of teeth. Body weight, using weigh-bands, of these animals was recorded twice, at an interval of six months Height at withers and body length were also measured. Blood samples were taken and ELISA test on serum was done to elucidate bulls´ candidates´ trypanosomosis infection status.

3.3.2. Selection committees and selection process

To allow full participation of farmers in the process of selection, selection committees consisting of local men (3), women (2) and one young person less than 25 years of age were set up in each locality. Bulls were put into 3 groups based on the index, putting equal emphasis weight and weight gain, both corrected for age. Group 1 were bulls with high weight and fast growth, group 2 were bulls with average weight and growth and group 3 were bulls with low weight and slow growth. Unfortunately, trypanosomosis status was not available for many bulls at the time of selection and therefore could not be included in the ranking process. Committees were asked to choose across the 3 groups their 1st, 2nd and 3rd best bulls and give the reasons of choice. Before choosing, information on the grouping baset of weight and growth was provided to the committee. Committees were previously informed that the best bulls will be awarded. To minimize conflictd of interest, the committee members having their bulls among the candidates were asked to abstain from the choice.

Due to practical constraints like the accessibility of some villages and the difficulties to group all the animals in the same place, each locality was subdivided in two or three locations of selection. The best bulls of each location were brought to central place of the locality for the final selection of the 3 top bulls of the community.

3.3.3. Data analysis

The computer program "Statistical Analyses Software (SAS)", version 9.4 was used to analyze the data. A general linear model (GLM) was employed for body weight and weight gain considering the linear and quadratic effects of the covariate age. An index was calculated putting equal weights on current body weight, corrected for age, and growth over the last six months. Animals were ranked based on the residual of the model with animals being heavier and or growing faster than others based on their age ranked higher.

3.4. Results

The ranking of bulls by the linear model in the three areas is presented in Tables 1, 2 and 3. Of a total of 103 young bulls recorded, 63 were presented for selection. They consisted of 33 bulls in Bouroum-Bouroum, 15 in Loropéni and 15 in Kampti. Table 4 presents the results of the first round of selection by the committee in the three areas. The bulls presented were chosen as the best in each location based on the opinion of the committee and these qualified for the final selection in a central location. Committees chose predominantly (50%) animals from the top group according to the index, but also of groups 2 (40%) and 3 (10%) were considered top according to farmer opinions.

Table 3. 1: Bulls ranked based on their age, weight, gain and residuals in Bouroum-Bouroum

Site	Group	ID	Age	Weight	Gain	Weight_R	Gain_R	Overall_R_std
Bouroum I	1	11014	4.5	225	31	19.50	58.80	78.29
	1	11306	4.0	210	12	11.37	38.13	49.50
	1	11099	5.0	215	0	11.43	25.98	37.41
	1	11312	4.0	194	4	-4.63	30.13	25.50
	1	11323	3.0	162	4	3.51	16.41	19.92
	2	11143	5.0	206	-41	2.43	-15.02	-12.59
	2	11038	5.0	213	-59	9.43	-33.02	-23.59
	3	11070	5.0	135	0	-68.57	25.98	-42.59
	3	11051	4.0	154	-56	-44.63	-29.87	-74.00
	3	11030	4.5	225	-123	19.50	-95.21	-75.71
	3	11137	3.0	128	-87	-30.50	-74.60	-105.08
Bouroum II	1	11663	3.0	190	47	39	16.25	55.25
	1	765	5.0	248	38	30	14.00	44.00
	1	11719	3.0	174	46	23	15.25	38.25
	1	11852	3.0	174	34	23	3.25	26.25
	1	767	4.0	178	28	10	14.00	28.00
	2	11707	3.0	135	36	-16	-5.25	-10.75
	2	726	3.0	154	14	3	-16.75	-13.25
	2	703	3	122	30	-29	-0.75	-29.75
	2	11877	3	140	12	-11	-18.75	-29.75
	2	757	3	119	27	-32	-3.75	-35.75
	3	11876	5	188	10	-30	-14	-44

Site	Group	ID	Age	Weight	Gain	Weight_R	Gain_R	Overall_R_std
Bouroum III	**1**	11508	5.0	243	28	29.84	27.30	57.15
	1	11510	3.0	190	2	46.05	1.41	47.46
	1	11450	3.0	158	15	14.05	14.41	28.46
	1	11435	4.0	194	8	10.05	7.41	17.46
	1	11468	4.0	194	12	25.42	-7.42	17.93
	1	11467	3.0	154	8	10.05	7.41	17.46
	2	11491	4.0	178	0	9.42	4.51	13.93
	2	11507	4.0	188	-14	19.42	-9.49	9.83
	2	11534	4.0	174	0	5.42	4.51	9.93

ID= Identity of the bulls (ear tag), Age= age in years, Weight= Body weight, Gain= six months body weight gain, Weight_R= Residual of body weight, Gain_R= Residual of gain, Overall_R_Std= Overall residual standardized

Table 3. 2: Table 3.2. Bulls ranked based on their age, weight, gain and residuals in Loropeni

Site	Group	ID	age	Weight2	Gain	Weight_R	Gain_R	Overall_R_std
Loropéni I	**1**	11769	4	296	20	26.67	19.33	2.12
	1	11793	3	230	24	17.60	20.20	1.84
	1	11765	3	235	10	22.60	6.20	1.19
	2	11743	3	220	5	7.60	1.20	0.35
	2	11788	4	248	8	-21.33	7.33	-0.35
	3	11748	3	220	-15	7.60	-18.80	-0.83
	3	11744	4	264	-26	-5.33	-26.67	-1.77
	3	11750	3	157	-5	-55.40	-8.80	-2.55
Loropéni II	**1**	3511	3	166	26	19.0	7.0	2.26
	2	3518	4	198	20	-25.5	0.5	-1.03
	3	3510	3	128	12	-19.0	-7.0	-2.26
Loropéni III	**1**	252	4	290	50	20.5	18	2
	2	250	3	290	60	0.0	0	0
	3	274	4	249	14	20.5	-18	-2

ID= Identity of the bulls (ear tag), Age= age in years, Weight= Body weight, Gain= six months body weight gain, Weight_R= Residual of body weight, Gain_R= Residual of gain, Overall_R_Std= Overall residual standardized

Table 3. 3: Bulls ranked based on their age, weight, gain and residuals in Kampti

Site	Group	ID	Age	Weight	Gain	Weight_R	Gain_R	Overall_R_std
	1	3257	3	272	45	24.4	14.2	2.88
	1	3658	3	260	35	12.4	4.2	1.13
	1	3231	5	320	-10	0.0	0.0	0.00
Kampti I	2	3358	3	248	31	0.4	0.2	0.04
	2	3355	4	247	13	-0.0	-0.0	-0.00
	3	3256	3	246	29	-1.6	-1.8	-0.28
	3	3659	3	312	14	-35.6	-16.8	-3.77
	1	3798	3	276	51	29.11	181.86	2.33
	1	11393	3	257	87	10.11	208.73	1.95
	2	3828	3	272	42	25.11	115.19	1.68
Kampti II	2	3247	3	296	19	49.11	-48.64	1.15
	2	11416	4	330	5	-0.00	0.00	0.00
	2	11375	5	330	40	0.00	-0.00	-0.00
	2	3251	3	240	18	-6.89	-56.39	-0.66
	3	11398	3	182	37	-64.89	-23.83	-2.21
	3	11367	3	220	-10	-26.89	-242.44	-2.73

ID= Identity of the bulls (ear tag), Age= age in years, Weight= Body weight, Gain= six months body weight gain, Weight_R= Residual of body weight, Gain_R= Residual of gain, Overall_R_Std= Overall residual standardized

Table 3. 4: Bulls selected by the committees in each selection site in three areas.

Site	Group	ID	Age	Weight	Gain	Weight_R	Gain_R	Overall_R_std
Bouroum I	**2**	11038	5.0	213	-59	9.43	-33.02	-23.59
Bouroum II	**1**	11852	3.0	174	34	23	3.25	26.25
Bouroum III	**1**	11435	4.0	194	8	10.05	7.41	17.46
Loropéni I	**3**	11748	3	220	-15	7.6	-18.80	-0.829
Loropéni II	**2**	3518	4	198	20	-25.50	0.50	-1.03
Loropéni III	**1**	252	4	290	50	20.50	18	2
Kamti I	**1**	3257	3	272	45	24.4	14.2	2.88
	2	3358	3	248	31	0.4	0.2	0.04
Kampti II	**1**	11393	3	257	87	10.11	208.73	1.95
	2	11416	4	330	5	-0.00	0.00	0.00

ID= Identity of the bulls (ear tag), Age= age in years, Weight= Body weight, Gain= six months body weight gain, Weight_R= Residual of body weight, Gain_R= Residual of gain, Overall_R_Std= Overall residual standardized

Table 5 shows the results of final ranking of bulls in the three sites. In Bouroum-Bouroum, a Baoulé bull of 5 years of age with a weight of 213 kg was selected. Blood analysis revealed that this bull was positive to trypanosomosis. In Loropéni, a crossbred bull of 4 years old and weighted about 290 kg and negative to trypanosomosis was selected. In Kampti, an apparent Zebu bull of 4 years old and 330 kg but positive to trypanosomosis was ranked first.

The selection of top bulls was followed by workshops with participating communities to discuss the use of the bulls for breeding in the community. Decision was taken by the farmers which bulls to keep for breeding and which ones to castrate or sell out, to avoid undesired mating.

Table 3. 5: Characteristics of the best bulls selected in the three areas

Site	ID	Age	Weight	Reason of choice
Bouroum	11038	5	213	Pure breed / Lobi Head and Neck well developed Beautiful coat color Good for mating and ploughing
Loropeni	252	4	290	Bods size and appearance Best market value Zebu
Kampti	11416	4	330	Body size and appearance Development of hump

ID= Identity of the bulls (ear tag), Age= age in years, Weight= Body weight

3.5. Discussion

This selection process shows some homogeneity in terms of preference for bulls and cattle in the study area. The reason for ranking bulls best was size, appearance and the potential growth of relatively young animals. This is in accordance with the interest of farmers for bigger animals. In addition to size, other body characteristics like coat pattern, horns shape were reported by farmers to be reasons for preference. Several studies investigated the preference and criteria of selecting cattle in African and reported high preference for body size and appearance (Janssen-Tapken, 2009; Mapiye et al., 2009; Ndumu et al., 2008; Wurzinger et al., 2006; Yakubu et al., 2019). Growth as criterion for selecting bulls for breeding purposes has also been reported by Ayantunde et al. (2007). In addition to productive traits, farmers are also interested in the beauty of an animal

(Ndumu et al., 2008; Wurzinger et al., 2006). Furthermore in Eastern Africa, in addition to color and horns, size of hump has been also cited as criteria for selecting breeding males (Janssen-Tapken, 2009). However, in the South West of Burkina Faso, farmers did not show preference for specific coat color.

In addition, on these common reasons there was specific interest depending on the site and the specificity of farmers. Bouroum-Bouroum and Loropéni people were more oriented toward crop production and payed attention to the ability of bulls for ploughing. Draft power and traction ability have been reported as preferred trait in male selection in East and West Africa (Ejlertsen et al., 2013; Janssen-Tapken, 2009; Traoré et al., 2017; Zewdu et al., 2018). In Kampti, the migrant Fulani people emphasized some characteristics considered by them to be associated with fertility, like testicle size of bulls. Fertility of bull is also reported in Eastern Africa (Janssen-Tapken, 2009).

Resistance to diseases plays an important role in actual management of breeding herds. Farmers keeping Ankole cattle in Uganda considered resistance to East Coast Fever a very important trait (Ntumu et al., 2008). For the current bull selection, we aimed at having a trypanosomosis test avaialbe for each butt as an additional indicator for selection. The data were only partly available at the time of bull selection and could therefore not be included. It was planned to have this information available at the time of bull selection, and to also check the status of selected bulls for the sexually transmitted pathologies brucellosis and tuberculosis, to avoid their spreading through sharing of bulls.

3.6. Conclusion

The findings of this study show clearly that participatory selection for genetic improvement is possible in the low input cattle production system of the South West of Burkina Faso. The criteria established by farmer communities for the selection of best bulls depend on that population and the types of reared animals. Also, farmers' preferred traits do not result necessarily in genetic gain for growth performance. In our study area, a good management system for the selected bulls needs to be identified to help the different communities share their genetic resources and improve the performance of their animals. For this, it is also necessary to diagnose the status of selected bulls in terms of sexual pathologies like brucellosis and tuberculosis to avoid their spreading through sharing of bulls. Community management rules should be clearly defined about the use of selected bulls. Joint use of bulls and bull exchange are still being negotiated by farmers, as it is not a customary practice in the region.

3.7. Acknowledgements

The authors are grateful to the Government of Austria that sponsored this study through the Austrian Partnership for High Education and Research (APPEAR). They extend their thanks to the farmers of Bouroum-Bouroum, Loropéni and Kampti for their willingness to collaborate in this study and the government extension workers for their facilitation.

Chapter 4

Population structure, inbreeding and admixture in local cattle populations managed by community-based breeding programs in Burkina Faso

Dominique Ouédraogo[1,2], Salifou Ouédraogo-Koné[1], Bernadette Yougbaré[2,3], Albert Soudré[4], Bienvenue Zoma-Traoré[1,2], Mészáros Gábor[2], Negar Khayatzadeh[2], Amadou Traoré[3], Moumouni Sanou[3], Okeyo Ally Mwai[6], Maria Wurzinger[2], Anna Pamela Burger[5]*, Johann Sölkner[2]

[1]Institut du Développement Rural (IDR), Université Nazi Boni (UNB), BP 1091, Bobo-Dioulasso, Burkina Faso

[2]Division of Livestock Sciences, Department of Sustainable Agricultural System, University of Natural Resources and Life Sciences, Vienna, Gregor-Mendel Str. 33, A-1180, Vienna, Austria

[3]Institut de l'Environnement et de Recherches Agricoles (INERA), BP 8645, Ouagadougou, Burkina Faso

[4]Unité de Formation et de Recherche en Sciences et Technologies (UFR/ST), Université Norbert Zongo, BP 376, Koudougou, Burkina Faso

[5]Research Institute of Wildlife Ecology, Department of Interdisciplinary Life Sciences, University of Veterinary Medicine Vienna, Savoyenstrasse 1, 1160 Vienna

[6]International Livestock Research Institute (ILRI), PO Box 30709, Nairobi 00100, Kenya

*Corresponding author:

Tel: +43-(0)1-25077-7141; Fax: -7941

E-mail: pamela.burger@vetmeduni.ac.at

Journal of Animal Breeding and Genetics: Accepted

4.1. Abstract

High throughput genomic markers provide an opportunity to assess important indicators of genetic diversity for populations managed in livestock breeding programs. While well- structured breeding programs are common in developed countries, in developing country situations, especially in West African countries, where on-farm performance and pedigree recordings are rare, genomic markers provide insights to the levels of genetic diversity, including levels of introgression by other breeds and inbreeding. In this study, we analyzed key population parameters such as population structure, admixture and levels of inbreeding in three neighboring populations of African taurine and taurine x Zebu crosses managed by community-based breeding programs in the South-West of Burkina Faso. The three populations were pure Baoulé (called Lobi locally) in sedentary production systems, Baoulé x Zebu crossbreds in sedentary systems and Zebu × Baoulé crossbreds in transhumant production systems, respectively. The total sample analyzed included 631 animals and 38,207 single nucleotide polymorphisms (SNPs) after quality control. Results of principal component and admixture analyses confirmed the genetic background of two distinct ancestral populations (taurine and zebuine) and levels of admixture in all three breeding populations, including the presumably pure Baoulé group of animals. Inbreeding levels were moderate, compared to European dairy and beef cattle populations and higher than those of Brazilian Nellore cattle. Very few animals with inbreeding levels indicating parent-offspring or full sib mating were observed, inbreeding levels indicating half sib mating were also rare. For the management of breeding populations, farmers were advised to exchange best young bulls. The crossbreeding levels of presumably pure Baoulé animals are of concern to the breeding program due to the high level of endangerment of pure African taurine cattle populations across West Africa. Future rounds of bull selection in the community-based breeding program will make use of genomic information about admixture levels.

Key words: Breeding, Burkina Faso, Cattle, Inbreeding, Structure, Admixture, SNP

4.2. Introduction

Zebu (*Bos indicus*) and taurine (*Bos taurus*) are the main indigenous cattle genetic resources across a wide range of agroecological zones in West Africa. Local taurine cattle types of African ancestry are genetically distinct from European taurine cattle (Decker et al., 2014; Kim et al., 2020) and are typically very small in body size (Traoré et al., 2015). The African taurine cattle are only kept in the tsetse-infested and trypanosomosis endemic Sudano-Guinean area due to their tolerance to trypanosomiasis (Soudré et al., 2013). The desire of farmers to increase the body size of their cattle has led to an increasing crossbreeding of the taurine with heavier bodied Sahelian Zebu cattle in both the transitional Sudan-Sahel and the Southern Sudano-Guinean areas (Traoré et al., 2015). The crossbreeding is often practiced indiscriminately and thus threatening the genetic integrity of taurine cattle in the area (Alvarez et al., 2014).

In the South of Burkina Faso, use of Sahelian Zebu to “upgrade” Baoulé cattle- which are also locally called Lobi cattle, through crossbreeding now threatens the existence of local Lobi cattle breed. The Lobi cattle plays an important cultural role for the Lobi ethnic people, and is therefore a critical heritage for these people, besides serving as a source of income and savings. The cattle are used for ploughing and constitute an important asset for socio-cultural ceremonies such as dowry and marriage related gift exchanges among families, for which Zebu type animals are not accepted (Mopaté, 2015). Urgent need for conservation, including within breed improvement of this locally adapted breed is therefore necessary in avert the on-going genetic erosion, which if unchecked will significantly limit its capacity to cope with changes to production environments (Edea et al., 2013). Since 2016, three community-based cattle breeding programs; one for pure Baoulé and two for crossbreeds (i.e. Baoulé x Zebu crosses) have been implemented with the overall aim to increasing the animals’ body size and improving trypanotolerance (Ouédraogo et al., 2020a). The pure Baoulé program has been established in the sedentary pure Baoulé system (SPB) in which the farmers are natives of the local area and they keep pure Baoulé cattle. The other two programs with crossbreds have been set up, firstly in the sedentary mixed breed system (SMB) in which farmers are native, but keep pure taurine Baoulé as well as crossbreeds, and secondly in the transhumant Zebu and crossbred system (TZC), with predominantly migrants, who are mostly the Fulani people, who keep the Zebu and some crossbred animals(Ouédraogo et al., 2020b). However, the breeding management is not controlled very well, with replacement breeding bulls being mostly recruited from within these very herds, thus making the systems potentially highly susceptible to inbreeding.

Genetic characterization of livestock breeds is a strategic and critical first step in in the development of a national/regional plan for the management of any Animal Genetic Resource (FAO, 2007). Characterization provides the key information needed to inform and guide breeding program design, decisions on to the genetic improvement options and the sustainable management and utilization options for such resources (FAO, 2007; Madilindi et al., 2019a).

Genetic diversity information is essential for the control of inbreeding and for effective utilization and exploitation of a breed's specific characteristics (Makina et al., 2014). To mitigate the global environmental changes such as climate change, use of locally adapted breeds and their improvement are reasonable options for coping with the extreme and unpredictable effects of climate change, especially biological stresses such as increased disease incidence, famine and drought (FAO, 2010; Madilindi et al., 2019b).

Inbreeding refers to mating of parents who share one or more recent common ancestors (Curik et al., 2014). Understanding and control of inbreeding are key factors of genetic improvement strategies because increasing inbreeding reduces genetic variation and leads to inbreeding depression (Ferenčaković et al., 2013a).

Genetic markers have widely been used for the genetic characterization of West African cattle, including microsatellites (Alvarez et al., 2014; Kassa et al., 2019; Soudré, 2011) and single nucleotide polymorphisms (SNP) (Gautier et al., 2009; Tijjani et al., 2019). However, such markers have not yet been used to inform implementation of local cattle breeding programs. The aim of this study was to use high-throughput genomic markers to understand the current genetic make-up of local cattle populations involved in community-based breeding programs for pure Baoulé and their crosses with Fulani Zebu cattle breeds in South Western part of Burkina Faso.

4.3. Materials and Methods

4.3.1. Study area, sample collection and DNA extraction

EDTA blood samples were collected from 658 animals in the South Western region of Burkina Faso. The animals were part of three breeding programs implemented in three production systems in the area: sedentary pure Baoulé (SPB) in the district of Bouroum-Bouroum (BB), sedentary mixed breed (SMB) in the commune of Loropéni (PL) and transhumant Zebu and crossbreds (TZC) systems in the commune of Kampti (PK) respectively (Figure 1.1). In this study animals in SPB system were considered as pure African taurine (Baoulé), while animals in the other two production systems were considered as crossbred (Zebu × Baoulé). DNA was extracted from EDTA blood samples using the MasterPure^{TM} DNA Purification Kit for Blood Version II (Biozym Scientific, Oldendorf, Germany) following the manufacturer's protocols.

4.3.2. Genotypes and data filtering

Genotyping was conducted using the Illumina Bovine SNP 50K Bovine BeadChip, featuring 53,714 SNPs. PLINK 2.0 (Chang et al., 2015; Purcell et al., 2007; Saravanan et al., 2019) was used to perform sample and SNP base quality control. SNPs were arranged according to the ARS-UCD1.2 reference genome. Samples with more than 10% missing genotypes (genotype call rate < 90%), and SNPs with minor allele frequency (MAF) < 0.01 and deviation from Hardy Weinberg Equilibrium with Fisher's exact test (HWE p-value < 10^{-6}) were filtered and not used in the downstream analysis. After filtering, 38,702 SNP and 631 animals (343 in SPB, 156 in SMB and 132 in TZC) were included in downstream analyses. For the estimation of genomic diversity (observed and expected heterozygosity), each population was filtered separately for individual and genotype call rates above 90%, respectively, resulting in 46,618 SNPs in SPB, 46,523 SNPs in SMB and 46,475 SNPs in TZC. Finally, a symmetric identical by state (IBS) matrix was created with PLINK to identify any potentially related individuals.

4.3.3. Genetic diversity, population structure, and admixture analysis

Principal component analysis (PCA) and admixture analysis were performed to infer the population structure and admixture among the three cattle populations based on the filtered SNP. Individual-based PCA was performed for a *genlight* object through the function *glPca* in the R package Adegenet *v2.1.1* and the *s.class* option was used to represent principal components of pre-defined groups (Jombart, 2008; Jombart and Collins, 2015), and to plot the first three eigenvectors. We used maximum likelihood estimation of individual ancestries implemented in the AMDIXTURE *v1.3.0* program (Alexander et al., 2015), to determine the proportion of admixture and potential gene flow among the 3 cattle populations (*i.e.* production systems). In order to infer the most preferable number of clusters (K) for the three populations we ran ADMIXTURE from

K=2 to K=10 and evaluated the smallest cross validation (CV) error. Expected (H_E) and observed (H_O) heterozygosities for each population were estimated in Adegenet using the *summary* function for a *genind* object. The R package dartR (Gruber et al., 2017) was used to convert a *genlight* into a *genind* object.

4.3.4. Effective population size

Effective population size (Ne) is a genetic parameter that aids the understanding and modeling of the evolutionary history of the population and the genetic mechanism underlying complex traits (Hayes et al., 2003; Zhang et al., 2020). In this study, the relationship between variance in Linkage Disequilibrium (LD) and effective population size (N_e) was used to infer ancestral and recent effective population sizes. The N_e was estimated using SNeP software (Barbato et al., 2015) that allows the estimation of N_e trends across generations using SNP data that corrects for sample size, phasing and recombination rate based on the formula (Corbin et al., 2012).

$$N_{T(T)} = \left(4f(c_{(t)})\right)^{-1}(E[r_{adj}^2|C_t]^{-1} - \alpha$$

Where N_T is the effective population size T generations ago calculated as $T = \left(4f(c_{(t)})\right)^{-1}$ (Hayes et al. 2003) , C_t is the recombination rate for specific physical distance between markers calculated by SNeP (Barbato et al. 2015) using default value (1Mb ~1cM), $r_{adj}^2 = r^2 - (\beta_n)^{-1}$ where r_{adj}^2 is the LD value adjusted for the sample size (n), $\beta = 1$ is the default value for unknown phase and α is as correction for the occurrence of mutation (α = 2.2 as suggested by (Corbin et al., 2012)).

4.3.5. Identification of runs of homozygosity (ROH)

ROH are long homozygous stretches of DNA in the genome that are induced by transmission of identical haploid segments from a common ancestor of both parents of an individual. PLINK 2.0 code and the cgaTOH function (Zhang et al., 2013) were applied to compute ROH summary statistics and to calculate genomic inbreeding coefficients. The numbers of allowed missing and heterozygous genotype calls were dealt with according to ROH length, following (Ferenčaković et al., 2013b). The genomic inbreeding coefficient of each individual was calculated as:

$$F_{ROH} = \frac{L_{ROH}}{L_{AUTOSOME}}$$

Where L_{ROH} is the total length of all ROH in the genome of an individual, where the regions contain the minimum specified length of segments containing successive homozygous SNP, and $L_{AUTOSOME}$ refers to the specified length of the autosomal genome covered by SNP on the chip. In this study, we used ROH with minimum lengths of 1, 2, 4, 8 and 16 Mb, translating into 50, 25, 12.5, 6.25 and 3.125 generations of ancestry (Curik et al., 2014). Differences of inbreeding levels among populations were tested using Kruskall-Wallis tests. Pairwise comparisons were performed with Wilcoxon tests using R version 3.6.3.

4.4. Results

4.4.1. Genetic diversity, population structure, admixture, and effective population size

Principal Component Analysis was carried out to determine genetic relationships within and across the populations based on allele frequencies and levels of heterozygosity. We projected the genetic variation of each animal on the first three axes inferred from a principal component analysis (PCA) and incorporated production system information (SPB, SMB and TZC) for all samples (Figure 2). The three principal components (PC1, PC2 and PC3) explained 12.10% of the total variation. PC1 explained 10.47% of the total variation and showed that the main structuring is between the SMB population and the populations of the other two systems (SMB and TZC). PC2 described 0.82% of the total variation and reflected the genetic diversity among the populations of the SMB and TZC. Overall, there was no strict differentiation between the three populations.

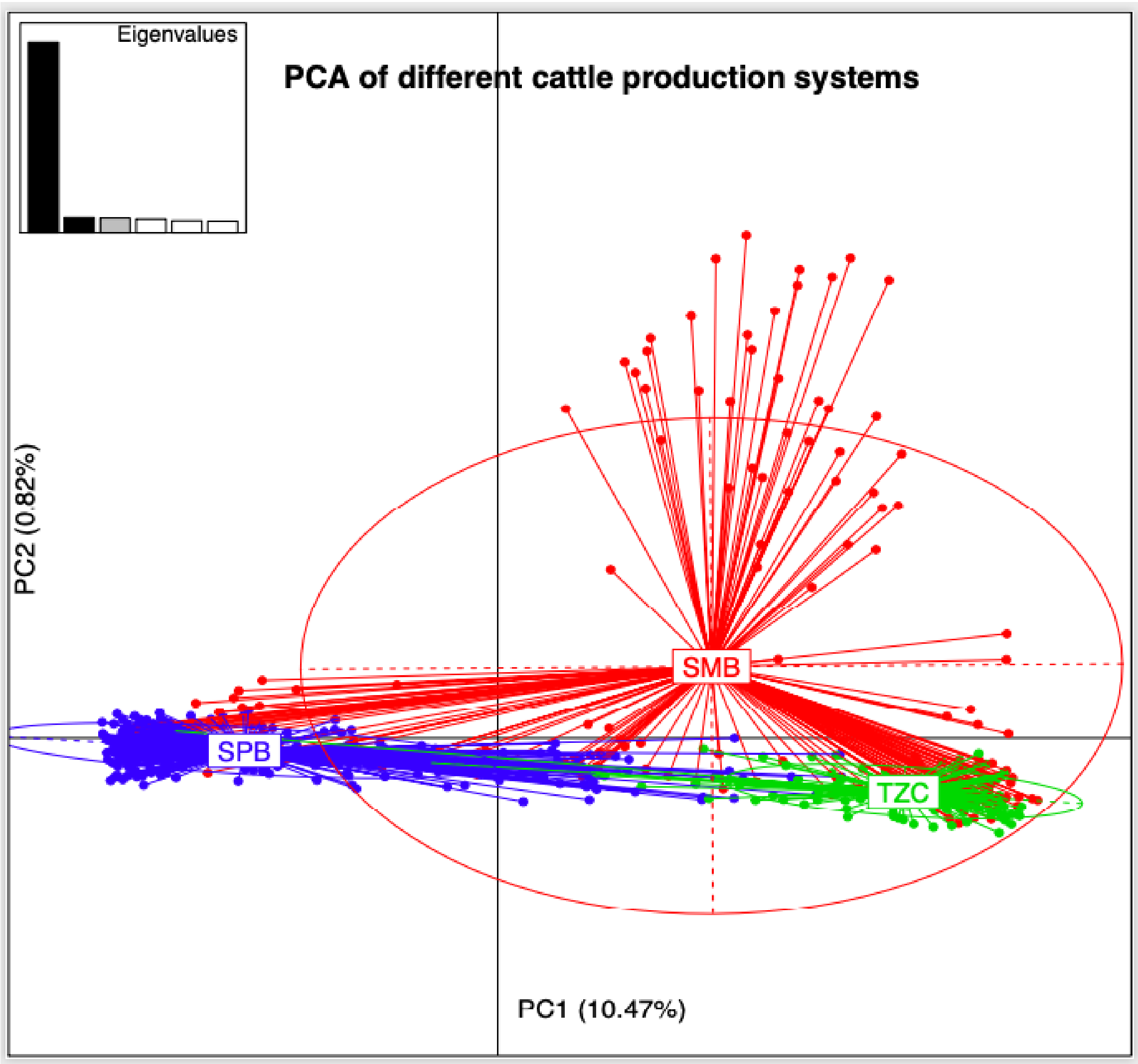

Figure 4. 1: Princical component analysis obtained from 631 individuals and based on 38,207

SNPs to represent populations pre-classified according to phylogenic clustering. Individuals are plotted according to their coordinates on the first two components. The first two PCs (PC1-PC2) explained 10.47% and 0.92% of the total variation, respectively. Elipses refer to the distribution of individuals within the groups. Population of Sedentary pure Baoulé system (SPB) is in blue and populations of Sedentary mixed breed system (SMB), Transhumant Zebu and crossbred system (TZC) are in red and green respectively.

Admixture analysis was performed to investigate the extent of admixture of animals in the three production systems. Based on the lowest cross validation error (CV), the best solution seemed to be nine clusters. However, regarding the history of the different populations and the practice of crossbreeding in the area, we chose to plot the admixture results for two and three assumed ancestries, K=2 and K=3 (Figure 3). For K=2 the samples were split in two groups which are presumed pure Baoulé animals in SPB and crossbreeds in the other two systems. Results revealed the presence of admixed individuals in each population/production system, confirming the PCA plots. For K=3, a subgroup of animals became visible in the second cluster correlating with the individuals separated by PC2 (Figure 2). Almost all of these individuals were owned by a single breeder and 34% of them (16 out of 47 animals) showed higher levels of relatedness (0.800-0.862) than all other investigated cattle (0.729-0.838). The estimated levels of genetic diversity (H_E/ H_O) within each of the three populations ranged from 0.290/ 0.278 to 0.327/ 0.310 and were lowest in the sedentary Baoulé cattle population (Table 1).

Effective population sizes estimates (N_e) predicted from linkage disequilibria of adjacent SNP for the current generation were lowest (37) for the crossbred SMB population, somewhat higher for TZC (53) and highest for the pure Baoulé population, SPB (79). N_e values were predicted to have been much higher for past generations.

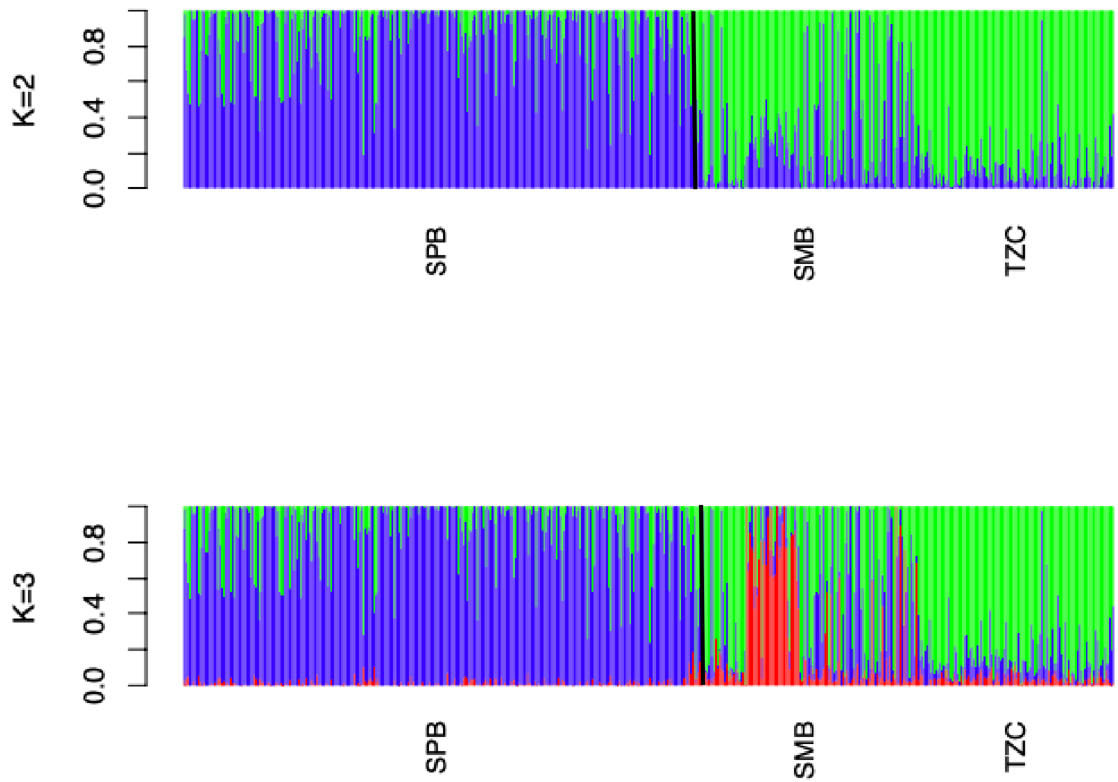

Figure 4. 2: Results of admixture analysis on 631 individuals and 38,207 SNPs with an inferred number of cluster K=2 and K=3 respectively.

Each individual is represented in a single bar. The black line divides the Baoulé cattle population of the Sedentary pure Baoulé system (SBP) from the crossbred populations in Sedentary mixed breed (SMB) and Transhumant Zebu and crossbred (TZC) systems.

Table 4. 1: Genetic diversity, expected (HE) and observed (HO) and effective population size (Ne) within the three cattle populations in the South West of Burkina Faso

PS	N	H_E (SD)	H_O (SD)	*Ne_1*	*Ne_5*	*Ne_20*	*Ne_50*
SPB	343	0.290 (0.175)	0.278 (0.172)	79	216	556	1009
SMB	156	0.327 (0.169)	0.309 (0.164)	37	114	308	709
TZC	132	0.319 (0.169)	0.310 (0.169)	53	217	584	887

PS: Production System, SPB: Sedentary pure Baoulé, SMB: Sedentary mixed breed, TZC: Transhumant Zebu and crossbred, N: Number of individuals, H_E/ H_O: expected/ observed heterozygosity, SD: Standard Deviation, Ne_1, Ne_5, Ne_20, and Ne_50 are the effective population sizes for the current generation, 5, 20 and 50 generations ago.

4.4.2. Run of homozygosity characteristics and genomic inbreeding

Genomic inbreeding coefficients (F_{ROH}) at different length categories (>1Mb, >2Mb, >4Mb, >8Mb, >16Mb) were analyzed for the three populations. The detailed statistics of genomic inbreeding coefficient (F_{ROH}) are presented in Table 2. The genomic inbreeding coefficients of individual animals at different ROH lengths ranged from 0.000 to 0.404. Populations were significantly different ($P<0.05$) for F_{ROH1}, F_{ROH4} and F_{ROH8}, yet, differences were quite small. The distribution of the animals according to levels of inbreeding is shown in Figure 4. Only one animal each (i.e. <1%) in the three systems was likely a product of parent-offspring or full sib mating ($F_{ROH8}>0.25$) and 3-5% were likely products of half sib mating ($F_{ROH8}>0.125$).

Table 4. 2: Descriptive statistics of the genomic inbreeding coefficients by ROH category of the three cattle populations in the South West of Burkina Faso

	SPB		SMB		TZC	
	Mean (SD)	Range	**Mean** (SD)	Range	**Mean** (SD)	Range
F_{ROH1}	**0.106** (0.056)^{a}	0.014-0.375	**0.093** (0.056)^{b}	0.009-0.361	**0.098** (0.045)^{c}	0.020-0.404
F_{ROH2}	**0.042 (**0.05)	0.000-0.332	**0.039** (0.051)	0.000-0.301	**0.037** (0.043)	0.001-0.364
F_{ROH4}	**0.027** (0.048)^{a}	0.000-0.311	**0.024** (0.049)^{b}	0.000-0.277	**0.020** (0.043)^{ab}	0.000-0.357
F_{ROH8}	**0.021** (0.043)^{a}	0.000-0.287	**0.019** (0.045)^{b}	0.000-0.255	**0.014** (0.040)^{b}	0.000-0.349
F_{ROH16}	**0.016** (0.037)	0.000-0.252	**0.015** (0.039)	0.000-0.252	**0.011** (0.036)	0.000-0.341

PS: Production System, SPB: Sedentary pure Baoulé, SMB: Sedentary mixed breed, TZC: Transhumant Zebu and crossbred, SD: Standard Deviation.

a, b, c: FROH not sharing superscripts within the same column indicate significant difference at P < 0.05. FROH were not significantly different in rows without superscripts.

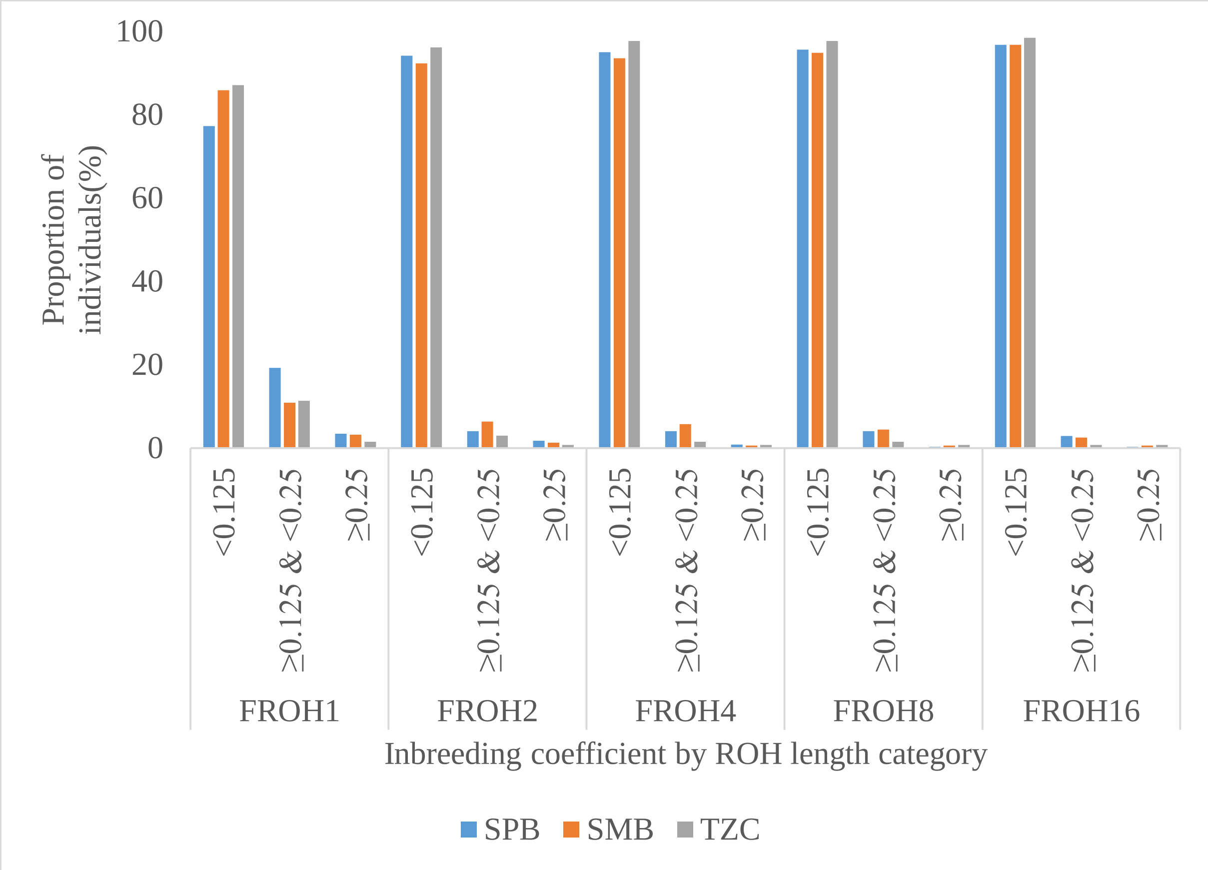

Figure 4. 3: Distribution of the 631 individuals by level of genomic inbreeding coefficient by ROH category.

The blue color represents the individuals of SPB (Sedentary pure Baoulé system) and the orange and gray colors represent the individuals of SMB (Sedentary mixed breed system) and TZC (Transhumant Zebu and crossbred system) respectively.

4.5. Discussion

4.5.1. Population structure and admixture

The principal component analysis (PCA) distinguished the pure taurine Baoulé animals in the SBP system and the crossbred animals in the SMB and TZC systems, respectively. The fact that the proportion of variance explained by the first principal component (10.47%) is much larger than that explained by the second (0.82%) is an indicator that two ancestries (taurine and zebuine) are driving the differentiation of the animals in the three locations. The clustering clearly reflects the prior status and knowledge about the three locations/systems, i.e. SBP farmers keeping mostly pure Baoulé, TZC keeping mostly Zebu and SMB being in between. Lack of distinct separation of groups suggested that gene flow freely occurs among these three populations, as was observed in and reported for groups of cattle in semi-arid regions of Algeria and Morocco (Boushaba et al., 2018). The gene flow was confirmed by admixture analysis, which showed levels of admixture in these different populations. Previous investigations have already reported evidence of Zebu introgression in West African taurine cattle breeds. Indeed, Decker et al. (2014) reported that presumed taurine cattle in Western Africa feature 0% to 19.9% indicine ancestry with an average of 3.3%. In Burkina Faso, the degree of introgression of White Fulani zebuine cattle genes into Lobi taurine was estimated to be 24.3% and that of Gudali zebuine in N'Dama taurine was reported to be 11% by Alvarez et al. (2014). A similar study of taurine breeds in Benin showed on average 20% of introgression by Zebu (Kassa et al., 2019). This admixture of cattle in the South West of Burkina Faso may be explained by historical and on-going breeding practices in this area. The admixture of the population of SPB in which farmers are native and keep their traditional taurine Baoulé is likely due to uncontrolled mating of animals, given the communal use of pasture lands or grazing as well as watering points (Ouédraogo et al., 2020b). Admixture levels in this system support the assertion that, under the current production systems, maintaining a genetically distinct population of pure Baoulé animals in this area is difficult. SMB farmers, who are also native, originally kept their native taurine Baoulé, but their desire to increase the body weights and presumably productivity in terms of meat production has continuously led them to introduce Zebu genes through crossbreeding, with the local herds increasingly being more crossbred. Kassa et al. (2019) explained the introgression of zebuine cattle in Benin by changes in farming practices, including the recruitment of Fulani people as herdsmen in non-Fulani areas. Fulani people have also been employed as herdsmen in the SMB system of the current study. Scheper et al. (2020)

also argued that transhumant Zebu keepers, mostly Fulani, contributed to Zebu admixture of local taurine breeds in Benin. Conversely, the admixture of the TZC population may be interpreted as introgression of taurine genes into Zebu blood. In this system, cattle owners are members of the Fulani ethnic group from the North of the country who settled in the area with their Zebu several years ago and over time have changed their lifestyle from nomadic to transhumant. They only seasonally move between the two locations, and put up and use semi-permanent housing structures in both locations. In a previous study, Ibeagha-Awemu et al. (2004) reported levels of introgression of African taurine genes of 7.5%, 15.5%, 8.1%, 8.5%, 38.2% respectively into White Fulani, Red Bororo, Sokoto Gudali, Wadara, and Adamawa Gudali Zebu types.

Regarding effective population size, N_e, the lowest value for the admixed SMB population is according to population genetics theory. Nei and Li (1973) showed that when isolated populations begin to exchange genes through migration, linkage disequilibrium tends to increase temporarily even for neutral loci. Similar patterns were observed in purebred and crossbred buffalo populations, see Deng et al. (2019).

4.5.2. Genetic diversity and inbreeding levels

Levels of genetic diversity and inbreeding are of great interest in managed livestock populations. We therefore estimated the genetic diversity in each population representing different production systems, and as expected, the lowest H_E/ H_O values were identified in the sedentary Baoulé cattle population of Bouroum Bouroum (SPB; Figure 3), while the sedentary mixed breeds and transhumant crossbred populations showed higher levels of heterozygosity (Table 1). Taking into consideration the ascertainment bias (Pérez O'Brien et al., 2014) of the Illumina Bovine SNP 50K Bovine BeadChip, which was designed based on eight European taurine and one African indicine breed, we compared the heterozygosity levels detected in the three populations with those observed in other taurine and indicine breeds over a global range (Orozco-terWengel et al., 2015). Among other Western African breeds, the H_O (0.278) estimated in native Baoulé from Bouroum Bouroum was slightly higher than results previously obtained in several N'Dama populations (0.209 - 0.237), Lagune populations (0.183) and previously genotyped Baoulé populations (0.216). Compared to European taurine breeds, the H_O value, obtained in this study for Baoulé population was within the range of values found in Jersey (0.263-0.277) or Brown Swiss (0.280) cattle in Europe. Due to the aforementioned ascertainment bias, the levels of heterzygosity in indicine breeds as has been shown in Nelore cattle (0.161) or Zebu Borono (0.241) and Zebu Fulani (0.240) (Orozco-terWengel et al., 2015), were expected to be lower than in the taurine breeds. The observed higher levels of heterozysity (0.310) in this study are most likely due to the human desired and induced admixture between taurine and indicine breeds within the different production systems (Figure 3).

High-throughput genotyping and ROH analysis provide a good tool for accurately estimating inbreeding levels, even in absence of pedigree information (Curik et al., 2014). So far, only few ROH studies have been performed for cattle in Africa. The few examples include those reported by Jemaa et al. (2018) and Purfield et al. (2012). Purfield et al. (2012) reported that African breeds had a tendency to have low F_{ROH}, compared to European cattle types, but the West African taurine breeds (Baoule, Lagune, N'Dama and Somba) showed high variability in individual ROH levels within breed. The authors attributed these higher ROH levels within the African taurine breeds to the open village breeding systems, in which animal tend to mate more randomly and consanguineously than would be the case if the animals were kept in more confined and independent herds, thus some of the animals exhibiting a pattern of ROH levels consistent with being highly inbred. Bororo and Fulani Zebu animals showed similar patterns, low levels of inbreeding in general, but a very small number of highly inbred animals found as well. Similar patterns of generally low inbreeding levels with some outliers were also found for a group of North African cattle populations by Jemaa et al. (2018).

In the current study, we found F_{ROH} close to 0.10 at a minimum ROH length of 1 Mb, corresponding to 50 generations of ancestry, for all three populations. Mean inbreeding levels for a ROH length >4 Mb (i.e. 12.5 generations of ancestry) ranged from 0.020 to 0.027. While population differences were relatively small. The Baoulé population in Bouroum-Bouroum (SPB) displayed significantly higher F_{ROH} with minimum ROH lengths of 1, 4, and 8 Mb, compared to the two other populations. Population differences were not significant for F_{ROH2} and F_{ROH16}. This results was unexpected because during focus group discussions before and during implementation of community-based breeding programs, the transhumant Fulani cattle keepers in Kampti (TZC) claimed to mostly use bulls born within their own herds, thus we expected high levels of inbreeding caused by such practices, including possibilities of parent offspring or half sib mating (Ouédraogo et al., 2020b). Indeed, only one animal each (i.e. <1%) in the three systems was likely resulted from parent-offspring or full sib mating (F_{ROH8}>0.25), while 3-5% were likely products of half sib matings (Figure 4).

Compared to well managed European cattle breeds, F_{ROH} in this study were lower than observed in Brown Swiss, Holstein and Italian local dairy cattle breeds, close to what was reported for Fleckvieh, Norwegian Red and Tyrol Grey and higher than results reported in Polish Red, Limousin and Simmental (Ferenčaković et al., 2013a, 2013b; Mastrangelo et al., 2016; Szmatola et al., 2016). Zebuine Nellore cows of Brazil showed lower F_{ROH1} values (0.046) compared to those of the current populations (Zavarez et al., 2015). The moderate levels of inbreeding in the study area despite recruiting and using bulls born within the herds could be due to a relatively short time of bull use (i.e. bulls being used for only very short periods before being sold off for slaughter) thus limiting mating of related animals. In addition, the communal grazing and watering also provide opportunities for cross-herd mating, thus lowering inbreeding coefficients. It was also reported that exchange of best young bulls between herds is common but should be strongly encouraged in the community-based breeding programs in the three study regions.

A similar study in African goats, kept under presumably similar village community systems, showed substantially lower inbreeding coefficients (F_{ROH2}=0.037, average over a range of populations) contrary to what was expected in populations in which breeding is not controlled (Nandolo et al., 2019). The higher inbreeding coefficients obtained in this study could indicate that cattle herds in these systems may be managed more strictly than flocks of goats in many village systems across Africa.

4.6. Conclusion

The results of this study support the existence of two main ancestries. i.e. taurine and zebuine in the cattle populations in the South West of Burkina Faso according to the production systems, with various levels of admixture. The different populations show proportions of admixture due to on-going traditional breeding and grazing practices. The cattle population in the sedentary “pure” Baoulé system includes a number of animals with Zebu proportions higher than expected. Although Lobi farmers emphasized the need for keeping their Baoulé pure, thus prioritizing conservation of this local cattle breed, crossbreeding continues to take place, with crossbred bulls being unintentionally being used because the farmers are not able to physically determine the breed admixture levels. To mitigate this, development and deployment of affordable and quick genotyping methods are ongoing, to support selection of candidate breeding bulls using either SNP chip or a small set of ancestry informative markers, as part of the community breeding initiative. Our findings also show moderate inbreeding levels, which are comparable to some well-managed European dairy and beef cattle breeds. It must be noted that those levels of inbreeding are the result of traditional breeding, not the community-based breeding programs, implemented too recent to have an effect. Upon implementation of community-based breeding programs, farmers have been encouraged to exchange selected bulls to minimize the mating of related animals.

4.7. Data availability statement

Quality controlled Bovine 50k SNP chip data, including 38702 SNP of the 631 animals included in this study was uploaded to DRYAD. The dataset has been assigned a unique identifier, doi:10.5061/dryad.2z34tmpj3 and is accessible via this temporary link: https://datadryad.org/stash/share/170ziMEzuc9BT23KZJedDtgjXemGi0pnXaDn8AB3UW4.

4.8. Acknowledgements

This study was funded by Austrian Partnership in High Education and Research for Development (APPEAR) through project 120 *LoCaBreed: Local cattle breed of Burkina Faso, characterization and sustainable use*. We are thankful to the farmers in the study area for their collaboration and to the extension workers for their facilitation in data collection.

4.9. Authors contribution

SJ, WM, MG, BPA, SA, TA, O-KS, MOA conceived the study. OD, YB and ZBL collected the samples, BY and SM extracted the DNA, OD, BY, KN, MG, BPA performed data analysis and OD wrote the manuscript. All authors provided valuable discussions, commented and approved the final manuscript.

4.10. Conflict of interest

All authors declare that there are no competing interests.

4.11. Ethical statement

The blood samples were collected with the consent of animals' owners and using approved veterinary process in Burkina Faso to avoid animals suffering.

Chapter 5

Genetic improvement of local cattle breeds in West Africa: a review of breeding programs

Dominique Ouédraogo[1,2]*, Albert Soudré[3], Bernadette Yougbaré[2,4], Salifou Ouédraogo-Koné[1], Bienvenue Zoma-Traoré[1,2], Negar Khayatzadeh[2], Amadou Traoré[4], Moumouni Sanou[4], Gábor Mészáros[2], Pamela Anna Burger[5], Maria Wurzinger[2], Okeyo Ally Mwai[6] and Johann Sölkner[2]

[1]Institut du Développement Rural (IDR), Université Nazi Boni (UNB), BP 1091, Bobo-Dioulasso, Burkina Faso

[2]Division of Livestock Sciences, Department of Sustainable Agricultural System, University of Natural Resources and Life Sciences, Vienna, Gregor-Mendel Str. 33, A-1180, Vienna, Austria

[3]Unité de Formation et de Recherche en Sciences et Technologies (UFR/ST), Université Norbert Zongo, BP 376, Koudougou, Burkina Faso

[4]Institut de l'Environnement et de Recherches Agricoles (INERA), BP 8645, Ouagadougou, Burkina Faso

[5]Research Institute of Wildlife Ecology, Department of Interdisciplinary Life Sciences, University of Veterinary Medicine Vienna, Savoyenstrasse 1, 1160 Vienna

[6]International Livestock Research Institute (ILRI), PO Box 30709, Nairobi 00100, Kenya

*Corresponding author:

Tel: +43 688 648 471 43

E-mail: ouedom@gmail.com

Sustainability Special Issue "Suitable Management of Animal Genetic Resources": Submitted

5.1. Abstract

Cattle is one of the most important livestock species in West Africa, providing multiple services to farmers and contributing to national economies. Over time, a range of breeding strategies has been implemented to improve the productivity of cattle, ultimately improving the livelihood of farmers. These strategies have had various effects regarding the environmental and socio-economic specificities of an area. In this review, we investigated different experiences in cattle breeding in West Africa. From N´Dama cattle in Mali, Senegal, and the Gambia to Azawak Zebu, Fulani Zebu, and taurine Baoulé cattle in Burkina Faso, different experiences are presented and discussed. Meat and milk performances for both taurine and Zebu cattle and trypanotolerance ability in addition for taurine cattle were the main breeding objectives. Close nucleus schemes implemented in some cases showed some limits and those programs evolved toward open nucleus schemes. Community-based approach recently implemented seems promising. Definition of realistic breeding objectives, involvement and cooperation of stakeholders are still the challenges of breeding programs in this area. All strategies reported in written documents reviewed here relied on external funds and implemented as development or research projects. Their continuity is uncertain after the projects´ life cycle which is often too short to allow the realization of genetic progress. For sustainable breeding programs of local cattle breeds continued governmental support is strongly advocated.

Keywords: Breeding strategies, Cattle, Local breeds, West Africa

5.2. Introduction

Africa is rearing about 300 million heads of cattle, representing about one fifth of the world cattle population (Dessie and Mwai, 2019). In West Africa, cattle population was estimated about 74.3 million in 2017 according to FAOSTAT (FAOSTAT, 2019). Cattle play major socio-economic and cultural roles for people. They represent a major source of animal protein (milk and meat), provide draft power, thus support crop farming, and fertilizer through manure, which is also used as fuel by some communities (Mwai et al., 2015). Cattle production contributes strongly to the farmers' livelihoods in this region.

Sub-Saharan Africa is home to a large population of indigenous cattle (Rewe et al., 2009). About 180 breeds of cattle including 150 indigenous breeds, introduced exotic and commercial composites have been recognized in this sub-continent (Rege et al., 1996; Rege and Tawah, 1999). In West Africa, 63 local and 23 exotic cattle breeds were reported (DAD-IS, 2019). Adapted to local environmental conditions, indigenous breeds represent a unique reservoir of genetic resources for the continuous improvement of livestock productivity in Africa and elsewhere (Hanotte et al., 2009). However, most indigenous breeds are characterized by low productivity. The low productivity of indigenous cattle could be attributed to poor genetic potential, inadequate nutrition, poor health services and management problem (Gamaniel et al., 2019). Thus, production of goods such as milk in the different countries is grossly inadequate to meet the growing demand of the population, which results in importation of dairy products to sustain such demand.

To improve cattle productivity in West Africa, diverse breeding strategies and policies have been implemented. As in many developing countries, the most common approach implemented has been centralized breeding schemes, entirely managed and controlled by governments – with minimal, if any, participation by farmers (Haile et al., 2018, 2011). However, few examples of successful cattle breeding programs exist in Sub-Saharan Africa (Rewe et al., 2009). Previous studies investigated cattle breeding programs implemented in the area, of which trypanotolerant N´Dama cattle breeding programs in Senegal, Mali, and The Gambia (Bosso, 2006; Bosso et al., 2009, 2007; Camara, 2019; Camara et al., 2020, 2019, 2018; Dempfle and Jaitner, 2000; Jaitner et al., 2003) are well known. Nevertheless, experiences exist with other breeds and different breeding schemes (Ouédraogo et al., 2020b, 2020a), meriting comparative review.

The review is structured in three parts. First, an overview is given about cattle breeds, traits and production systems on the sub-continent. The core of the review is a rather detailed presentation of six previous and ongoing breeding programs with local cattle breeds. Scientific publications and unpublished materials (project reports) related to the subject, are exploited (previously unpublished project reports are provided in Supplementary Materials). Informal discussions via email were held with stakeholders and former employees of some projects. Context, breeding objectives, breeding schemes applied, and genetic progress achieved are presented for each of the cases. For the N´Dama genetic improvement programs in Senegal and Mali (Cases 1 and 2), the description provided here is largely a translation from French of the documents of Camara (Camara, 2019) and Camara et al. (Camara et al., 2020).

5.3. Review

5.3.1. Cattle breeds, traits, and production systems in West Africa

The origin, characteristics, and distribution of African cattle are well documented and widely reported in the literature (Dessie and Mwai, 2019; Kim et al., 2020; Rege et al., 1996; Rege, 1994; Rewe et al., 2009). Morphologically, African cattle breeds may be subdivided into two main classes which are the humped *Bos indicus* and the humpless *Bos taurus* and three combinations which are Sanga (stable cross of *Bos indicus* × *Bos taurus*) and Zenga (stable cross of Sanga × *B. indicus*) and composite lines, which are recent derivatives between breeds, including crosses with exotic temperate breeds (Hanotte et al., 2009). Socio-economic and environmental factors such as use of animal traction and cultural preferences including religion, ecology and feed availability, disease and parasite pressure are the major drivers of cattle distribution (Blench, 1999).

In West Africa, most cattle production is carried out in the Sahel, the agricultural zone between the Sahara Desert and the coastal rain forest. This area represents a unique geo-climatic territory including very different ecological areas within a few hundred kilometers (Traoré et al., 2015). Cattle belong mainly to the humped Zebu and humpless taurine types. West Africa has 13 Zebu breeds inhabiting dry savanna zone and Sahelian belt and 11 taurine breeds including Longhorn N´Dama and Kuri breeds and 9 Shorthorn breeds widely distributed in moist savanna and sub-humid coastal forest belt (Hanotte et al., 2009; Rege et al., 1996). However, this traditional distribution of cattle in the region was perturbed over time with the continuous change of environmental and economic contexts. During recent decades, marked by frequent drought events in the Sahel, many pastoralists migrated and settled with their Zebu in humid and sub-humid areas (Boutrais, 2007; Jabbar et al., 1998; Kamuanga et al., 2001; Traoré et al., 2015, 2017). Nowadays, the Zebu type is widely expanded across the different agro-ecological areas of West Africa (Table 1). Indeed, in addition to taurine types, Belemsaga et al. (Belemsaga et al., 2005) combining phenotypic description and concepts used by livestock keepers described 13 local Zebu cattle breeds have been in 7 countries belonging to CIRDES (Centre International de Recherche-Développement de l´Elevage en Zone Subhumide) area: N'dama, Kouri, the Baoule-Somba group, the Lagoon cattle group, Zebu Azawak, Zebu Maure, Zebu Touareg, Zebu Goudali, Zebu Bororo, Zebu White Fulani, Zebu Djelli, Zebu Fulani Sudanese and Zebu Gobra (Toronke). All these local breeds are used for multiple purposes, but mostly for beef production (Rege et al., 1996; Rewe et al., 2009).

Indigenous genetic resources are the base of cattle production in this continental region. They are characterized by various genetic traits, namely, their resistance to diseases and drought, their ability to walk long distances, their capacity to survive on poor pastures, and their fertility (Ahozonlin et al., 2019). Farmers exploit these adaptive traits for their production objectives. Milk, meat, and work are the main uses of cattle in this region (Rege et al., 1996). Cash income, draught power, ceremonial use / dowry, manure, milk and meat for household´ consumption, hides and skins, cultural beliefs are among the motivations of farmers with high variability of their importance according to the target group (Ejlertsen et al., 2013; Ouédraogo et al., 2020b; Traoré et al., 2017; Yakubu et al., 2019).

Taurine cattle are mostly found in the southern tsetse-infested Sudano-Guinean area of West Africa due to their tolerance to trypanosomiasis (Silbermayr et al., 2013; Soudré et al., 2013). Reared in sedentary systems, taurine cattle are used mostly for meat, socio-cultural needs and draught power except for N´Dama cattle which is also used for milk in some regions. In contrast Zebu cattle kept by Fulani in pastoral and agropastoral systems is more oriented toward milk due to its comparatively high milk production (Ouédraogo et al., 2020b; Traoré et al., 2017). However, in various areas, different cattle types are reared by farmers in mixed herd system to benefit from their complementarity. Baoulé cattle for example were preferred to Zebu in disease resistance and grazing ability while Zebu was preferred to Baoulé for traits such as milk yield, size, fecundity, weight gain and traction ability (Tano, 1998; Tano et al., 2003).

Table 5.1: Geographic distribution of West African native cattle breed and some of their performances

Type	Breed	Area / Countries	HMA	HFA	WMA	WFA	References
Taurine	N´Dama	Guinea, Mali, Senegal, Gambia, Cote d´Ivoire, Burkina Faso, Benin	95-120	90-115	220-360	180-300	(Camara, 2019; Gréma et al., 2017; Traoré et al., 2015, 2017)
	Baoulé/Lobi	Cote d´Ivoire, Burkina, Ghana	100-106	90-103	160-300	150-240	(Belemsaga et al., 2005; Gréma et al., 2017; Rege et al., 1996; Traoré et al., 2015)
	Kouri	Niger, Nigeria	140-180	126-145	500-750	360-450	(Belemsaga et al., 2005; Gréma et al., 2017; Rege et al., 1996; Traoré et al., 2015)
	Lagunaire	Bénin	89-106	85-103	180-280	165-262	(Rege et al., 1996; Traoré et al., 2015)
	Somba	Bénin, Togo	89-106	85-103	150-215	115-185	(Belemsaga et al., 2005; Dossa and Vanvanhossou, 2016; Rege, 1994)
	Bourgou	Bénin	-	112.1	-	-	(Alkoiret et al., 2011; Traoré et al., 2015)
	Muturu	Nigeria, Benin	85-95	83-93	-	-	(Blench, 1999; Gréma et al., 2017; Rege et al., 1996; Tijjani et al., 2019)
	Kuri	Niger, Nigeria	140-180	126-145	500-750	360-450	(Gréma et al., 2017; Rege et al., 1996)
Zebu	M´Bororo	Burkina Faso, Nigeria, Mali, Bénin, Niger	128,4	122.1	-	-	(Belemsaga et al., 2005; Moussa et al., 2017; Traoré et al., 2015)
	Azawak	Niger, Mali, Burkina Faso, Bénin	128-135	122-130	350-500	300-410	(Belemsaga et al., 2005; Rege et al., 1996; Traoré et al., 2015)
	White Fulani	Nigeria, Niger, Mali, Bénin, Ghana	130-152	118-138	425-665	250-380	(Belemsaga et al., 2005; Rege et al., 1996; Umar et al., 2020)
	Sudanese Fulani	Burkina, Bénin, Cote d´Ivoire, Mali, Togo	120-138	115-126	280-345	248-300	(Belemsaga et al., 2005; Moussa et al., 2017; Rege et al., 1996; Traoré et al., 2015)
	Goudali	Nigeria, Niger, Bénin, Burkina Faso, Ghana, Mali	-	178.2	-	388.42	(Belemsaga et al., 2005; Umar et al., 2020)

Gobra	Sénégal, Mali	130-144	124-140	300-350	250-300	(Belemsaga et al., 2005; Marshall et al., 2017; Ngono et al., 2018; Rege et al., 1996)
Maure	Mauritanie, Sénégal, Mali, Niger, Cote d´Ivoire	125-140	110-128	250-700	250-350	(Belemsaga et al., 2005; Marshall et al., 2017; Ngono et al., 2018; Rege et al., 1996)

HAM: Height at Withers of adult male, HAF: Height at withers of adult female, WAM: Body weight of adult male; WAF: Body weight of adult female

5.3.2. Cases of genetic improvement programs of local breeds in West Africa

The different experiences of breeding programs with local cattle breeds in West Africa is summarized in Table 2. This is not a full list of all cattle breeding strategies implemented in the area, these six cases were chosen based on the availability of documentation and related information.

5.3.2.1. Case 1: N´Dama in Senegal

Context and breeding objectives: This program was set up in Casamance and Kolda, the southern sub-humid area of the country in 1972 with the funding of "Fonds Africain de Coopération (FAC)" and the government of Senegal and the breeding objective was to improve beef performance of N´Dama cattle (Camara, 2019; Camara et al., 2020). To involve farmers and their objectives in the program, an Open Nucleus Genetic Improvement System was adopted in 1991 and milk performance and trypanotolerance were included in breeding objectives (Camara et al., 2020). However, trypanotolerance was not directly considered in the selection process (Camara, 2019). Since 2008 the program is under funding of African Development Bank and Food and Agriculture Organization (FAO) in the context of "Projet de Gestion Durable du Bétail ruminant Endemique (PROGEBE)" and the primary objectives of milk production and beef performance were maintained while taking into account the conservation of trypanotolerance of N´Dama cattle regarding its cultural and socio-economic importance (saving, dowry, insurance and gift).

Breeding scheme: several breeding schemes were implemented since 1972. In the current stage started in 2008, it is a 3 tiers open nucleus scheme: it consists of a selection unit and a multiplication unit mainly constituted by the herds of farmers from the cooperative of N´Dama cattle breeders (CASE N'Dama) and a dissemination unit (village herds) (Camara et al., 2018). One of the operational objectives was to keep a breeding unit with 200 females, 4 males with a change of inbreeding rate per generation, $\Delta F = 0.039$. This system allows introduction and performance testing of young bulls (12 – 24 months) from village herds. Unlike the previous schemes, farmers were involved through their association in providing candidates for the breeding unit, management of multiplication units and in the dissemination of the genetic progress.

Selection process: in the current open nucleus system, two preselection steps are done before the final selection at 36 months of age of bulls. Young bulls of 6 to 18 months are candidates for the preselection based on body weight and bulls weighing more than 150 kg at 18 months are preselected. Performance of preselected bulls is tested from 18 to 36 months based on daily gain. This scheme was intended to include hematocrit values in the selection index, but this was not implemented. The breeding program claims indirect selection for trypanotolerance due to the positive correlation of 0.40 to 0.70 between hematocrit and growth. Best Linear Unbiased Prediction (BLUP) indicates genetic gain of 0.43 kg per year for the weight at 36 months, heritability estimates were 0.07 to 0.12 for birth weight and weight at 36 months, respectively.

5.3.2.2. Case 2: N´Dama cattle in Mali

Context and breeding objectives: genetic improvement of N´Dama cattle started in 1975, aiming with the global objective to improve and conserve the trypanotolerant N'Dama cattle in its environment and specifically to improve its beef performance. Started as a government ranch, different systems were implemented over time. Like in Senegal, the current breeding program began in 2008 under funding of FAO and the African Development Bank through the PROGEBE (Camara, 2019; Camara et al., 2020).

Breeding scheme: from 1981 to 1986, a closed nucleus breeding system using mass selection in the ranch was implemented. Several constraints such as feeding and management costs in the ranching system led to reorientation to participatory management involving livestock technical services and farmers. Between 1991 and 1993, selected animals at the ranch were thus transferred to village farms to test the adaptability of the selected animals under village conditions and to strengthen the participation of farmers in the selection process by including their objectives and practices. This dissemination process consisted of a contractual system in which farmers must return the same number and sexes of animals after 10 years. A selection scheme based on an open village nucleus was established, but the program failed due to financial constraints. In 2008, PROGEBE implemented a new center based open nucleus selection scheme. The animals previously rented to farmers served to reconstitute the selection unit in the "Centre de conservation et de multiplication du bétail ruminant endemique de Médina Diassa (CCMD/BRE)".

Selection process: Animals were selected based on coat color and conformation. Unblemished fawn animals with good conformation (massive and stocky) were preferred. Animals meeting these conditions were selected based on their daily gain between 8 and 18 months and weight at 18 months over 150kg. Trypanotolerance ability was included in selection and low use of drugs was used as an auxiliary trait.

5.3.2.3. Case 3: N´Dama cattle in The Gambia

Context and breeding objectives: the program was initiated in 1994 and started in 1995 at the International Trypanotolerance Center (Bosso, 2006; Bosso et al., 2009, 2007; Dempfle and Jaitner, 2000; Jaitner et al., 2003). The aim of this program was to improve the welfare of the livestock owners and their families through better performance and increased productivity of their livestock (Bosso, 2006). The program was successively funded by Bundesministerium für Wirtschaftliche Zusammenarbeit (BMZ; Germany) from 1994 to 1998, the FAO until 2000, by European Union fund trough project named "Programme de Concertation de recherche-Développement de l´Elevage en Afrique de l´Ouest (PROCORDEL)" until 2008 and since 2008 by the African Development Bank and FAO in the context of PROGEBE (Camara, 2019; Camara et al., 2020). The breeding objectives of increasing meat and milk production without compromising cattle adaptation and resistance to disease were defined in participatory way with farmers. In addition to milk and meat, farmers showed interest for drought power and manure (Dempfle and Jaitner, 2000; Jaitner et al., 2003; Steglich and Peters, 2002).

Breeding scheme: an open nucleus scheme with 3 units was adopted. A selection unit located in 2 areas characterized by moderate and high persistence of tsetse flies, respectively. Relative favorable conditions in unit of the first site located at Kenaba allowed good birth and weaning rates. Trypanotolerance ability and adaptation of animals were tested in the second site at Bansang where the conditions were relatively hard.

Selection process: since 2008, a complex selection index including growth performance of young bulls and their relatives is used. In the first site, calves were selected based on their daily gain from 0 to12 months. Best bulls were selected in the second site using index including their daily gain from 15 to 36 months and the milk productivity of their dams (Bosso et al., 2007). Replacement of breeding males and females in the breeding unit was done using the 2 best bulls and 55 best females each year. The second-best bulls were sent to multiplication units while the non-selected bulls were sold to butchers. The selection was done in participatory way by the National Agricultural Research System team and the farmers. Genetic monitoring using BLUP model showed 0.40kg of annual genetic gain and heritabilities of 0.48 for body weight at 12 months of 0.28 for weight at 36 months.

5.3.2.4. Case 4: Azawak Zebu cattle in Burkina Faso

Context and breeding objectives: in the 1990s, programs and projects have been promoted in Burkina Faso to enhance local dairy production to contribute to the reduced importation of milk and dairy products, to exploit and valorize the genetic potential of local breeds, to fight against the deficiency of animal proteins in the diet of rural populations and to reduce poverty by improving farmer income. A development project named "Projet de Soutien a la Diffusion du Zebu Azawak" (Project to Support the Dissemination of Azawak Zebu) was implemented between 2000 and 2015 and its global strategy was to improve the potential of local dairy production by the introduction and the multiplication of pure Azawak Zebu animals to substitute the local Fulani Sudanese Zebu through continued backcrossing. Funded by the Belgium Technical Cooperation (BTC), the project has been implemented in 3 phases. However, the last phase (2011-2015), funded by the programme BKF of Luxembourg Development Cooperation was focused on pastureland degradation restoration. The program was carried out in 11 sites (communes) in the Sahel (Dori, Djibo, Yalgo, Gorom-Gorom, Bajni, Taparko, Arbinda, Kelbo, Pobe-Mengao) and central (Ziniaré and Ouagadougou) regions of the country, involving 329 farmers owning about 2400 animals. Farmers of each site were organized in Azawak Zebu breed associations and the 11 associations formed the National Union of Azawak Zebu Breeders. The expected results of this project were to increase the population of Azawak Zebu, to improve the genetic potential of Azawak Zebu, to increase milk and meat production through optimal management conditions, to improve the skills of Azawak Zebu farmers and to establish participatory genetic improvement strategy.

Breeding scheme: a dispersed nucleus scheme was implemented. Within breed selection was used for pure Azawak Zebu population while absorption crossbreeding was done between Azawak and Fulani Sudanese Zebu. Bulls used in the crossbreeding system were always Azawak Zebu.

Selection process: young pure Azawak Zebu bulls from 9 to 12 months of age were recruited for performance testing in a central station with capacity of artificial insemination. Parameters recorded were testicle size, chest girth, body weight and libido. All these bulls were trained for sperm collection and sperm quality was evaluated. At 30 months of age, a selection index was calculated including daily gain and libido. Bulls were ranked according to this index and selection was done by selection committee including technicians and farmers. The best bulls were selected and reintroduced in the herds as sires while non-selected bulls and crossbred bulls were destocked. Comparative evaluation between the start of the program and the end of the second phase showed that the number of animals per genotype increased by 20, 364, 500 and 483% respectively for pure Azawak Zebu, crosses F1, crosses F2 and pure Fulani Zebu. The increasing number of pure Fulani Zebu was due to the recruitment of females for crossbreeding, but globally the proportion of this genotype decreased from 65.8% in 2004 to 51.8% in 2007, indicating that the absorption crossbreeding was working. This was also confirmed by the appearance of crossbreds F3 in the breeding population. The birth weight of 20.5±3.4kg, 20.6±3.7kg, 20.9±2.4kg, respectively in pure Azawak Zebu, F1 and F2 crossbreds was significantly (<0.05%) higher than 18.9±3.4Kg in pure Fulani Zebu. Milk yield was evaluated for 186 days of lactation. The average milk productivity was 625±198kg, 516±218kg and 560±220kg in pure Azawak Zebu, F1 crosses and pure Fulani Zebu respectively (Tamboura et al., 2008).

5.3.2.5. Case 5: Sudanese Fulani Zebu cattle in Burkina Faso

Context and breeding objectives: the Sahel region of Burkina Faso is the traditional geographic area of Fulani Sudanese Zebu cattle; the most important cattle breed of the country. The project documents reported that for this type of cattle, while well adapted to the local harsh environmental conditions, the productivity decreased due to several constraints, among them the unsuitable genetic management (see supplementary materials 2, 3). Indeed, high levels of inbreeding were assumed, as the result from long period of bull use (7 to 8 years) and the choice of replacement bulls among the offspring in the same herd. In general, cows having low milk yield were not milked and returned to reproduction early, resulting in short calving intervals (12-18 months) contrary to cows producing more milk, which had long calving intervals (18-24 months), also due to lactation anoestrus. Without a selection strategy excluding individuals with low milk production, the number of offspring from such cows increased. To respond to this situation, a genetic improvement strategy was implemented through a development project named “Projet de Soutien au Développement du Zebu Peulh” (Project to Support the Development of Fulani Zebu). It was funded by the Belgian Technical Cooperation (BTC) and implemented by Veterinarians without Borders Belgium in collaboration with local Non-Governmental Organization (NGO) named “Association Nodde Noto”. The project started in 2005 and was implemented for 13 years in the Oudalan province. The objective was to control inbreeding and improve the productivity of Fulani Zebu through the setting up of a breeding program involving farmers to take advantage of their traditional knowledge on the adaptation of animals to difficult conditions of the Sahelian region to complement the technical criteria of selection. The project aimed to increase the productivity of

Fulani Zebu through better milk productivity per cow per lactation and fertility with the number of weaned calves per cow per year from 0.44 to 0.5. Selection criteria were determined in a participatory manner and farmers came up with a long list of possible traits. Therefore, the project team and stakeholders decided in collaboration with farmers to rank and keep the most important ones. For bulls, the preferred traits were milk production of the dam, body size, head and neck profile, large ears, long tail, and good conformation. For females, the traits retained were milk production, docility, large pelvis, large and well-fixed udder, long and soft teats, belly size and fertility.

Breeding scheme: this project implemented a dispersed nucleus breeding system (Mueller et al., 2015). The selection unit consisted of elite farmers selected by the project team regarding the availability of top breeding females with good maternal line in their herds, their good husbandry practices and their willingness to adopt the strategy of the project and to respect the rules set up. Farmers in the multiplication unit were selected by farmers' organizations. The project started with 28 farmers in the selection unit having 233 reproductive females and only 6 bulls that met the criteria of good breeding bulls according to the project criteria. Additional bulls were then bought by the project to provide all the 28 herds. The project planned to have a performance testing unit in which young bull candidates for the selection would be reared but this was not technically feasible and farmers did not agree with the idea, preferring to keep these young candidates in their herds. Decision was taken to allow farmers to keep their young bulls and barns were built locally in which performances of young candidates was periodically recorded and tested.

Selection process: in the selection unit, controlled mating system was implemented between the top females from good maternal lines and the selected bulls. Performances of young males from their offspring were recorded and young bulls ranked based on an index including growth, size, and sexual activity. Bulls were grouped in 4 groups according to their performances. The top bulls from group 1 were distributed to the farmers in breeding units, the second group to farmers for multiplication, the 3rd group sold to farmers who were not part of the breeding program and animals of group 4 were fattened and sold to market. A selection committee, consisting of 7 members, 3 farmers and 4 representatives from the Ministry of Livestock Resources and other professional structures, oversaw bulls' selection.

5.3.2.6. Case 6: Baoulé cattle and Zebu × Baoulé crossbreds in Burkina Faso

Context and breeding objectives: Baoule cattle, locally called Lobi, is the most important taurine cattle breed of Burkina Faso. As many West African taurine breeds, this small but trypanotolerant breed found in the Sudanese humid part of the country is currently under pressure due to indiscriminate crossbreeding with Zebu. Breeding programs have been implemented for local Baoulé cattle and crossbreds in the southwestern Burkina Faso since 2016 using a community-based approach (Ouédraogo et al., 2020a, 2020b). These programs were funded by the Austrian Development Agency (ADA) through Austrian Partnership for Higher Education and Research and Development (APPEAR) project LoCaBreed "Local cattle breeds of Burkina Faso – Characterization and sustainable use". One of the goals of this research and development project was to implement sustainable breeding programs to improve and conserve the local cattle breeds. Three breeding programs were implemented in three communities, corresponding to three production systems, and involved about 100 farmers owning about 2000 animals. One breeding program was for pure Baoulé cattle in sedentary system with native people in the commune of Bouroum-Bouroum and 2 breeding programs were for crossbreds, one in sedentary system with native people in Loropeni and one in transhumant system with migrant people in Kampti. Farmers´ traits preferences were investigated using participatory approaches, combining survey and own herd ranking of animals to define the breeding objectives (Ouédraogo et al., 2020b). These investigations showed that body size was the most important selection criteria confirming the interest of farmers for productive traits. Thus, growth performance (weight at given age, daily gain) was the main selection trait of these programs to meet the objective of improving body size. It was considered that fast growing young bulls are also trypanotolerant.

Breeding scheme: village breeding schemes were implemented, using the community-based approach (Mueller et al., 2015). This approach encourages strong participation of the farmers in all the different stages, from design to implementation. The village herd was considered as unit of selection. The selection was based on young males only.

Selection process: Body weight of young bull candidates was recorded twice in 6 months interval. A general linear model (GLM) was employed for body weight and weight gain, considering the linear and quadratic effects of age. An index was calculated putting equal weights on current body weight, corrected for age, and growth over the last six months. Animals were ranked based on this index with animals being heavier and or growing faster than others based on their age ranking higher (Ouédraogo et al., 2020a). Bulls were put into 3 groups based on the index. To allow full participation of farmers in the process of selection, selection committees consisting of local men (3), women (2) and one young person less than 25 years of age were set up in each locality. Committees were asked to choose across the 3 groups their 1st, 2nd and 3rd best bulls and give the reasons of choice. Before choosing, information on weight and growth of each group of bulls was provided to the committee. Committees were previously informed that the best bulls will be awarded. A total of 3 rounds of selection were done by 2020, involving about 200 candidates of which about 70 were selected and distributed for breeding.

Table 5.2: Characteristics of six cases of local cattle breeding programs in West Africa

	N´Dama in Senegal	**N´Dama in Mali**	**N´Dama in The Gambia**	**Azawak Zebu in Burkina Faso**	**Fulani Zebu in Burkina Faso**	**Baoulé and Baoulé x Zebu Crosses in Burkina Faso**
Period	1972 - ongoing	1975 - ongoing	1994 - ongoing	2000 -2015	2005 - 2018	2016 - ongoing
Breeding objectives	Meat, Milk and trypanotorelance	Meat and trypanotorelance	Meat, Milk and trypanotorelance	Milk	Milk and control of inbreeding	Meat and trypanotolerance
Animal selected	Males and females	Males	Males and females	Males	Females and Males	Males
Selection criteria	Milk performance Body wieght of males at 18 months Daily Gain at 18 -36 months	Coat color Body weight of males at 18 months Daily Gain at 18 -36 months	Milk performance in the 100 first days of lactation Daily Gain at from 0-10 months and 15-35 months	Daily gain and Libido at 30 months	Females and its maternal milk performance Daily gain and Libido at 30 months	Body weight at 3-5 years Daily gain in 6 months
Breeding scheme	Open nucleus	Open nucleus	Open nucleus	Dispersed nucleus	Dispersed nucleus	Village breeding
Number of tiers	3	3	3	2	2	1
Location of nucleus	Research Center	Genetic improvement center	Research Center	Genetic improvement center	Elite farms in villages	-
Size of nucleus	200 females 4 males	-	-	-	233 females 28 males	-
Recording	On station	On station	On station	On station	On farm	On farm
Genetic evaluation	BLUP in 2012	Yes in 1984	BLUP in 2007	No	No	Phenotype deviation
Participation of farmers	Breeding, multiplication, and	Multiplication and	Multiplication and	Dissemination unit	Selection criteria Recording	Selection criteria Recording

	dissemination units	dissemination units	dissemination units		Selection (selection committee)	Selection (selection committee)
Stakeholders involved	NGO Research center	NGO Genetic improvement Center, Government extension workers	NGO Research Center	NGO Genetic improvement center Research Institute	NGO Farmers´ organization Government central and extension services Genetic improvement center	Universities Research Institute Government extension services
Existence of breeding association	Yes	No	Yes	Yes	Yes	Being set up
References	[15–18]	[15–18]	[12–14, 19, 20]	Project reports (Tamboura et al., 2008)	Project reports	[21, 22]

5.4. Discussion

5.4.1. Breeding objectives and selection criteria

A breeding objective defines the direction in which the farmer aims to go towards satisfying the demand for specific products and services from the animal (Sölkner et al., 2008). In extensive smallholders' production system in which animals are kept for a variety of purposes with varying emphasis, valuing farmers' knowledge in the definition of breeding goals is required (Mueller et al., 2015). Lack of involvement of farmers in defining the breeding objectives was the main reason of failure of many livestock improvement programs (Kahi et al., 2005; Wurzinger et al., 2011). In the investigated cases of this study, meat, milk and trypanotolerance were the main breeding objectives (Table 2). In the cases of Fulani Zebu and Baoulé and crossbreds in Burkina Faso as well as N´Dama cattle in The Gambia, farmers' traits preferences were investigated in participatory manner at the start of the program (Jaitner et al., 2003; Ouédraogo et al., 2020b). Conversely, in the case of N´Dama, in Mali and Senegal the objective of improving beef performance was decided without involving farmers. Considering the interest of farmers in milk, the program in Senegal was reoriented including milk as one of the breeding objectives (Camara et al., 2020). In addition to productive traits, disease resistance was considered in programs for taurine cattle i.e in N´Dama cattle as well as in Baoulé and crossbred cattle in Burkina Faso. However, this trait was included differently according to the breeding programs. In Mali and Senegal, emphasis was put on animal coat color, in The Gambia young bulls' candidate were reared in infested areas while in Senegal and Baoulé and Zebu × Baoulé crossbred programs in Burkina Faso, the positive correlation between growth and disease resistance was taken into account, assuming that young bulls with good growth performance had better trypanotolerance. In the Fulani Zebu program in Burkina Faso, control of inbreeding was targeted while a study on the inbreeding level of the population was not done.

Definition of breeding objectives is a critical step that influences the success of a breeding program. In conventional market-oriented breeding programs, objectives are often directly derived from the economic values of the traits involved (Goddard, 1998). In traditional systems the multiple functionality of animals make the determination of breeding objectives is more complex and, breeding objectives are indirectly derived by analysing farmers´ traits preferences (Duguma et al., 2011; Ejlertsen et al., 2013; Gizaw et al., 2018; Haile et al., 2018, 2011; Ndumu et al., 2008; Ouédraogo et al., 2020b; Sölkner et al., 1998; Traoré et al., 2017; Wurzinger et al., 2006; Yakubu et al., 2019). In such systems, defining realistic, feasible and measurable breeding objectives which meet beneficiaries' needs is the main challenge. Including milk as breeding objective in N´Dama cattle was done to satisfy the interest of farmers in milk, but the low performance of this breed seemed not to fit with such objective. Furthermore, maintaining and improving taurine tryponotolerance has always been the concern of promotors of breeding programs in West Africa. Yet, including a good proxy of trypanotolerance in a selection index remains difficult. Contrary to productive traits, fitness traits in general and specifically disease resistance are difficult to record and to select for even in sophisticated breeding system (Heringstad et al., 2000). Moreover, among the farmers preferred traits, it is important to focus on few of them which represent the breeding goal, are heritable and easy to measure (Sölkner et al., 1998). In Zebu breeding programs in Burkina Faso (i.e. Sudanese Fulani and Azawak Zebu), the breeding traits were either to many (Azawak Zebu) or difficult to measure (i.e. libido in both). Even the promotion of good breeding practices could contribute to reduce inbreeding, with the lack of pedigree recording in extensive production system, including inbreeding level as breeding objective (i.e. Sudanese Fulani Zebu) seems very ambitious.

The final objective of any breeding program is to improve farmers' incomes and livelihoods. Several studies in West Africa reported that a key interest of farmers for keeping cattle is to earn cash income (Ejlertsen et al., 2013; Ouédraogo et al., 2020b; Traoré et al., 2017). Breeding programs in this area should have a holistic approach which include all the livestock value chain from production to market. In this context, market remains a big constraint for farmers. Gowane et al. (Gowane et al., 2019) reported that lack of market connectivity with breeders due to high dependence on local traders who control the prices of livestock discourages the objectives of breeding programs. Removing constraints and bottlenecks related to market could contribute to the success of breeding programs. However, in the investigated cases, the market aspect was apparently not enough emphasized. Strong links with the market will help farmers to adopt new technologies for health care and nutrition along with improved germplasm (Gowane et al., 2019).

5.4.2. Breeding schemes and selection process

Open nucleus, dispersed nucleus, and village breeding programs were implemented in the investigated cases (Table 2). In N´Dama cattle programs in Senegal and Mali, practical constraints led to the evolution of systems from closed to open nucleus schemes. Open nucleus breeding scheme allows the flow of animals in both directions from the nucleus to the population and vice versa while the closed scheme allows only the flow of animals from the nucleus to the population. In developing counties where performance recording at farm level is not practiced nucleus programs have advantages of allowing accurate recording and processing by which achieving efficient selection and high genetic gain (Guangul, 2014). However, to run such a program in a sustainable way it needs high infrastructure and technical input (Kosgey et al., 2006). Indeed, management of breeding unit in closed nucleus programs is costly, specifically the maintenance and feeding of animals and this caused them to fail in Mali and Senegal. Furthermore, farmers were not willing to bring their best animals to a breeding unit in central station (Kahi et al., 2005); as was the case of Sudanese Fulani Zebu program in Burkina Faso in which farmers were finally allowed to keep their bull candidates in their herds. On the contrary, in dispersed nucleus systems, such costs are minimized because animals are handled and managed by farmers themselves. While success of a nucleus program in Djallonke sheep with strong support of government and other sources as well as community participation is also reported in West Africa (Yapi-Gnaoré, 2000), many nucleus breeding programs in developing countries failed due to the lack of sustainable support and adequate involvement of the community (Kosgey et al., 2006; Kosgey and Okeyo, 2007; Wurzinger et al., 2011). Drawing lessons from this and regarding that community-based breeding programs have been successfully implemented in goats and sheep in similar context in Eastern and Central Africa (Duguma, 2010; Duguma et al., 2011; Guangul, 2014; Kaumbata et al., 2020; Mirkena, 2010; Mirkena et al., 2012; Nandolo et al., 2016), this approach was adopted for Baoulé cattle and Baoulé × Zebu crossbreds in Burkina Faso. This approach is suggested for the low input traditional smallholder farming system and it involves farmer participation in all steps of the implementation (Haile et al., 2018, 2011; Kahi et al., 2005; Mueller et al., 2015; Sölkner et al., 1998; Wurzinger et al., 2011). Different from a conventional top down strategy, community-based approach takes into account the indigenous knowledge of the communities on breeding practices and breeding objectives. Typically it is structured in single-tier with no distinction between breeding and production units, i.e. all farmers involved are breeders and producers (Gizaw et al., 2013). In community-based Baoulé and Baoulé × Zebu program in Burkina Faso, farmers were strongly associated in the different operations of the implementation. Considering village herd as breeding unit has the advantage of providing a large number of breeding candidates and increased selection intensity. Yet, working with a dispersed nucleus of very interested farmers and distributing the genetic gain achieved there to the village population has its own benefits (Mueller et al., 2015).

5.4.3. Stakeholders and farmers' involvement

The sustainability of activities related to animal genetic resources (AnGR) management depends largely on the participation of a ranges of stakeholders, both public and private (Leroy et al., 2017). Participation and strong collaboration of stakeholders are key for breeding program success. The main stakeholders in breeding programs include government, research organizations, Non-Government Organizations (NGOs), funding institutions and breeders/livestock keepers organizations (Camara et al., 2019; Kahi et al., 2005; Leroy et al., 2017; Lobo, 2019). Research organizations provide scientific support for setting breeding goals, identification, recording and for genetic and economic evaluation, as well as technological development; Governments, NGOs, funding institution, cover the role in financing, subsidizing and capacity building and farmers and their organizations are responsible of the breeding program management, genetic progress and breed conservation (Camara et al., 2019; Leroy et al., 2017). In this analysis it appeared that stakeholders were involved varyingly according to the cases. In the cases of N´Dama cattle, research institutions were relatively strongly involved in the setting of breeding objectives, in the redirection of breeding schemes and contributed to genetic evaluation through BLUP. In Burkina Faso, national research institute (INERA) and technical institute ("Centre de Multiplication des Animaux Performants (CMAP)") were involved in Azawak and Fulani Zebu project while the Baoulé and Baoulé × Zebu crossbred case was based on a research project involving two universities and one research institute in Burkina Faso and two universities in Austria. These institutions contributed to breeding objectives definition and the selection of breeding animals even no genetic evaluation was done. One of the factors limiting the contribution of research organizations in the promotion of new strategies and tools of genetic improvement in developing countries is often the lack of expertise (Ducrocq et al., 2018). In this sense the contribution of developed countries institutions in the capacity building and strengthening of those in developing countries is important. Training of doctoral students was reported in the cases of N'Dama cattle in Gambia and Baoulé and Baoulé Zebu crossbred program in Burkina Faso.

Strong participation of farmers in the activities is an important factor of the success of breeding program. Farmers were differently associated in different breeding activities in the breeding programs of this study. In The Gambia N´Dama and in the different programs in Burkina Faso, farmers were associated to selection of breeding animals. The selection committees in community-based Baoulé and Baoulé × Zebu crossbred program considered the different components of the society including gender aspect regarding the role of women in livestock activities. In smallholder production system in which farmers are mostly illiterate, their involvement should also be through breeders/producers' organizations. Lack of organization of breeders/producers is a challenge of development of breeding programs (Lobo, 2019). Breeders' organizations/associations could indeed contribute to self-maintainence and sustainability the breeding program. In the investigated cases, breeders' associations participated in the identification of the candidates for selection and in the dissemination of selected animals. In developing countries, development policies relative to animal genetic resources (AnGR) management should promote coordination among livestock keepers through creation and empowerment of cooperatives, associations, or community-based approaches (Leroy et al., 2017). Public support is still required in the early capacity development and external support from various stakeholders is needed to ensure long-term sustainability (Leroy et al., 2017; Mueller et al., 2015). All these breeding programs in the region were funded by outside donors and implemented as development or research projects. Consequently, some of these programs stopped at the end of the projects as it was in the cases of Fulani and Azawak Zebu in Burkina Faso. According to Lobo (Lobo, 2019), lack of resources was the reason of discontinuation of many programs in goats and sheep in Brazil. Genetic improvement programs are considered as investment projects, which required essential inputs and strong institutional support with sufficient funding from Government to sustain operations (Gowane et al., 2019; Kahi et al., 2005). Lack of follow up financial support from local governments is a major constraint of successful breeding programs in developing countries (Kosgey et al., 2006; Lobo, 2019). Furthermore, investment in breeding programs is limited due to the low interest of public sector and the farmers who always wait for public support (Lobo, 2019).

5.5. Conclusion

In this study we analyzed cattle breeding programs in West Africa, concentrating on six cases of programs with local breeds, implemented in the last 4 decades. Context, breeding objectives, implementation process including breeding schemes and the selection of breeding animals, stakeholders involved, success, limitations and lessons learnt of these programs were analyzed. Meat, milk, and disease resistance were the main breeding objectives of these programs. However, definition of clear and realizable breeding objectives was the main challenge of these programs as it is usually the case in extensive production systems. Different schemes including open nucleus and dispersed nucleus were applied with various levels of involvement of farmers. Most of these programs were sponsored by external funds, through development or research projects and some of these programs suffered of self-maintenance after the projects' lifespan. Several stakeholders such as NGOs, research institutions, universities, farmers' organizations, genetic improvement centers were involved, but in some cases their role were limited. It clearly appears that successful and sustainable cattle breeding programs in West Africa require strong and continued support of local governments and other stakeholders. Yet, the contribution of such breeding programs to the national economies through improved genetic resources can be substantial.

5.6. Author Contributions

Conceptualization JS, MW, MAO, AS, O-KS, PAB, AT, GM, OD; Methodology: JS, MW, OD; Information collection: OD; Writing: OD, JS; Visualization: JS, MW, MAO, AS, O-KS, PAB, AT, GM, OD, NK, BY, Z-TB, MS; Review-Editing: JS, MW, MAO, AS; Supervision: JS, MW, MAO, AS, O-KS, PAB, AT, GM. All authors have read and approved the final version of the manuscript for publication.

5.7. Funding

This research was funded by the Austrian Development Agency (ADC) through Austrian Partnership Program in High Education and Research for Development (APPEAR) project 120 (LoCaBreed: Local Cattle Breed of Burkina Faso – Characterization and Sustainable Use).

5.8. Acknowledgements

We would like to thank all the authors whose research findings were exploited in this paper. We are particularly grateful to Bognana Rigobert Taunsi, Konkobo Bernard and Doulkoum Eugène, former employees of Azawak and Fulani Zebu projects in Burkina Faso for providing all the literature and information.

5.9. Conflict of interest:

The authors declare no conflict of interest

Chapter 6

General discussion and conclusion

6.1. Introduction

Livestock is an important source of livelihoods for millions of people around the world. Indigenous genetic resources are the base of livestock production in most developing countries. Genetic improvement is a key factor to increase the productivity of indigenous animals to feed the growing demand for animal products and improve the livelihoods of cattle keepers. Community-based breeding implemented with success in small ruminant populations in Africa provides an option in developing countries where there is lack of infrastructure and routine recording systems. Genetic characterization is an important step that can guide and support the breeding decisions.

The aim of the four studies in this thesis was therefore to design and implement community-based breeding programs of local Baoulé and Zebu × Baoulé crossbreds in the South West of Burkina Faso by: 1) understanding the current breeding objectives and practices and their implications of the design of breeding program; 2) selecting bulls in participatory way to implement the breeding programs; 3) using high throughput genomic information to understand the current genetic make-up of the breeding populations; 3) reviewing breeding programs for local cattle breeds in West Africa.

The main hypothesis supporting this study was that community-based breeding strategies may be a suitable approach for the genetic improvement of local cattle breeds.

In this chapter, we reflect the major findings from the studies reported in this thesis and highlight the salient results. We furthermore discuss these studies and their potential implications and limitations.

6.2. Summary of the major findings

In **chapter 2**, we investigated the production systems, and we identified the specific preferred traits related to breeding objectives. The current characteristics of farmers, their herds and management strategies allowed the definition of three production systems in the study area which are sedentary pure Baoulé system (SPB), sedentary mixed breed system (SMB) and transhumant Zebu and crossbred system (TZC). These production systems reflect the current change of livestock production systems in West Africa under the influence of agroecological and socio-economic factors. Breeding practices such as bull selection within herd, castration, are occurring in the area. The most important criteria for selecting breeding animals were adult size / body weight, including calf growth, for both males and females. The importance of these criteria varied according to the production systems.

In **chapter 3**, we implemented the participatory selection of breeding bulls in the community-based breeding programs. Through the combination of a selection index based on growth performance at age and farmers' preference through selection committees, the best young bulls were selected. The results indicated that farmers were not only interested in genetic gain resulting in growth but also in other characteristics such as coat color patterns, horn shape and, also in the suitability of bulls for ploughing, particularly for farmers oriented in crop production.

In **chapter 4**, we explored the option of use medium density 50K SNP data to highlight the genetic parameters such as admixture, structure, and inbreeding levels of the breeding populations. The results supported the presence of two cattle ancestries i.e. taurine and zebuine, as expected, in our study area with various levels of admixture within the different populations, also in the presumably pure Baoulé population. Moderate inbreeding levels were also found, levels being in the range found in well-managed European breeds.

In **chapter 5**, we reviewed six cattle genetic improvement programs in West Africa. The programs for local taurine cattle were most oriented on beef performance and diseases resistance i.e. trypanotolerance and while breeding programs of Zebu cattle included milk production as a target trait. However, two of these programs lacked continuity due to the unsustainability of their funding system; suggesting that breeding programs need strong involvement and support of governments to produce the expected results.

6.3. Cattle production systems and breeding objectives

Livestock production systems and farmer lifestyle are continually mutating with the changes of socio-economic and environmental contexts. In West Africa, the droughts having occurred in 1970s and 1980s compelled pastoralists, mostly Fulani, to emigrate from northern Sahelian zones to southern humid savanna (Ayantunde et al., 2014; Blench, 1999; Boutrais, 2007; Traoré et al., 2015, 2017). This was accompanied by some changes in pastoralists and local farmers' lifestyle and livestock management including changes in herd composition with the introduction of local cattle genotype to adapt to the new ecology; but also crossbreeding between Zebus and local taurines both ways (Ayantunde et al., 2014; Boutrais, 2007; Houessou et al., 2019). Our findings in cattle production systems in the South West of Burkina Faso (**Chapter 2**) reflect prior knowledge on cattle production systems in this sub-continent region.

The findings of this study (**Chapter 2**) confirmed the multiple functionalities of cattle in low-input production systems and the heterogeneity of the breeding objectives depending on the farmers own characteristics. While earning cash incomes remains the main objective, sedentary people usually keeping local Baoulé put emphasis on social uses of cattle while migrant Fulani keeping more Zebu are more interested in milk. Local people keeping African taurine cattle most for meat, social and cultural needs, drought power, and the interest of Fulani Zebu keepers in milk were reported (Adoligbe et al., 2020; Majekodunmi et al., 2017; Mopaté, 2015; Mopaté et al., 2014). We also found that productive traits are the main interest of farmers regarding their criteria for selection of breeding animals. At the contrary, fitness traits such as disease resistance were less considered, despite the area reputed to be a trypanosomsis challenge area (Silbermayr et al., 2013; Soudré et al., 2013). Concordantly, previous studies pointed out the high importance of productive traits for extensive farmers in small ruminants (Duguma et al., 2011; Getachew et al., 2010) and in cattle (Bayou et al., 2018; Kassie et al., 2009; Ndumu et al., 2008; Ouma et al., 2007; Wurzinger et al., 2006; Yakubu et al., 2019; Zander and Drucker, 2008). Unlike our results, previous studies reported that disease resistance is more important than are production traits in West African humid regions (Tano et al., 2003; Traoré et al., 2017). Soudré et al., (2013) also reported that trypanosomosis is one of the most important diseases in the area. The low importance of disease resistance reported in this study may be explained by the various campaigns against tsétsé flies and the current frequent use of trypanocides and vaccinations by the Fulani Zebu keepers, reducing the potential impact of trypanosmosis disease in the area.

Several methods were used to study smallholders' farmers breeding animals' selection criteria to capture their breeding objectives. Most of these methods employed participatory approaches, and the combination of at least two methods is suggested (Haile et al., 2018, 2011; Ndumu et al., 2008). The heterogeneity of the results of survey and own herd ranking used in this study supports the need of combining methods.

6.4.Implementation of breeding program in cattle

In this thesis we implemented the participatory selection of bulls with a strong involvement of selection committees consisting of farmers only (**Chapter 3**). To meet the breeding objective of improving animal size, the selection index included the body weight by age as well as growth in the recent 6 months. Cattle body weight is known to have good heritability and is thus easy to change. The results of this experience show that while in the participatory definition of breeding objectives body size is most frequently mentioned by farmers, when it comes to select the best reproductive bulls, a range of additional criteria were used by farmers. This included animal appearance such as horns shape, coat color pattern, confirming the importance of these secondary traits for smallholders as reported in other regions (Getachew et al., 2010; Ndumu et al., 2008; Wurzinger et al., 2006).

Globally farmers in the study area showed high interest and strongly committed themselves in the implementation process of the community-based breeding program in general and in bull selection particularly. However, some issues were raised with Fulani people who have pastoralist lifestyle and cattle herds seasonally moving searching for grazing and water. Likewise, breeding programs failed to be established with pastoralists in Afar region of Ethiopia due to their mobility (Mueller et al., 2015). For this specific group, the selection might be scheduled in strategical periods of the year when animals are there; this could be at the beginning of the rainy season and the period after crop harvesting.

6.5.Genetic structure and admixture of the cattle breeding populations

Genetic diversity is an important aspect in the perspective of breeding programs. Today, the availability of throughput genomic data allows a better understanding of those parameters associated to genetic diversity. Using medium density 50K data we highlighted the structure and the admixture of our breeding populations (**Chapter 4**). The genes flow occurring among the three populations confirmed prior knowledge about the admixture of West African local indigenous cattle breeds (Alvarez et al., 2014; Decker et al., 2014; Ibeagha-Awemu et al., 2004; Kassa et al., 2019). This admixture is induced by the historical and on-going breeding practices characterized by frequent crossbreeding between taurine and Zebu. Crossbreeding is an important strategy for the adaptability and the productivity of indigenous cattle breeds. Indeed, combination of past taurine and recent indicine admixture-derived genetic resources is a root of the present success of African pastoralism (Kim et al., 2020).

6.6.Levels of inbreeding in the breeding populations

In this thesis it has been demonstrated that the levels of inbreeding in our breeding populations seem to be moderate (**Chapter 4**). These levels of inbreeding are not the consequence of our breeding programs implemented recently. Obviously, with uncontrolled mating under village conditions, mating of close relatives is much less frequent than commonly implied by the livestock community (Nandolo et al., 2019). Indeed, mating is occurring randomly in grazing and watering places. Yet, management of inbreeding becomes important with the implementation of controlled breeding, like the community-based cattle breeding programs in the South West of Burkina Faso. Intensive selection of bulls can increase the levels of inbreeding and lead to loss of genetic diversity as observed sometime with improved breeds in well-structured breeding programs (Makanjuola et al., 2020).

6.7.Cattle genetic resources management and improvement in West Africa

Genetic improvement is commonly considered as costly and not realizable in developing countries. Therefore, priority is mostly put on animal feeding and health, considered as major constraints of livestock production. However, sustainable livestock production cannot be reached by ignoring animal genetics, which is an important determinant of animal performance. Many tentative breeding programs failed for diverse reasons. In **Chapter 5** of this thesis we gave an overview of cases cattle breeding programs in western Africa. Several schemes were implemented for local taurine and Zebu cattle aiming to improve beef and milk performances and also disease resistance. Yet, funding system, lack of infrastructures and involvement of stakeholders still limited the success local cattle breeding programs.

6.8.Conclusion

This thesis showed that community-based breeding programs, previously implemented for small ruminants, are feasible indeed for the genetic improvement of local cattle breeds in developing countries. Farmers accepted the rationale of strict selection of male animals in the community being critical for genetic gain. Castration of non-selected bulls as well as exchange of selected bulls was acceptable; yet, actual implementation of those was not fully reached during the project period. While the research project driving the CBBP will be completed soon, infrastructures of the regional government, the advisory system as well as the farmer groups, have been established to furnish continuity. Still, its success will depend on the continued engagement of key persons, including members of the project team. As the cost of high throughput genotyping is getting very low, even to the standards of developing countries, genomic tools for predicting disease resistance and breed composition have a future in the context of community-based programs.

References

Adoligbe, M.C., Amaveda, M.A., Djimenou, D., Farougou, S., 2020. Muturu cattle breed management in the smallholder farming area of the Ouémé district in the south of Benin: rearing practices, objectives, and constraints. Trop. Anim. Health Prod. https://doi.org/10.1007/s11250-020-02320-8

Ahozonlin, C.M., Koura, B.I., Dossa, L.H., 2019. Determinants of Crossbreeding Practices by Cattle Farmers in South Benin, West Africa: Implications for the Sustainable Use of the Indigenous Lagune Cattle Population. Sustain. Agric. Res. 8, 101–109. https://doi.org/10.5539/sar.v8np2p101

Alexander, D.H., Novembre, J., Lange, K., 2015. Fast model-based estimation of ancestry in unrelated individuals. Genome Res. 15, 1655–1664.

Alkoiret, I.T., Yari, H.M., Gbangboche, A.B., Lokossou, R., 2011. Reproductive Performance and Milk Production of Girolando Cows in the Ranch of Kpinnou, South-West of Benin Republic. J. Anim. Vet. Adv. 10, 2588–2592.

Alvarez, I., Pérez-Pedal, L., Traoré, A., Fernandez, I., Goyache, F., 2015. African cattle do not carry unique mutations on the exon 9 of the ARHGAP15 gene. Anim. Biotechnol. 27, 9–12. https://doi.org/10.1080/10495398.2015.1053606

Alvarez, I., Traoré, A., Fernandez, I., Cuervo, M.A., Lecomte, T., Soudré, A., Kaboré, A., Tamboura, H.H., Goyache, F., 2014. Assessing introgression of Sahelian zebu into native Bos taurus breeds in Burkina Faso. Mol Bio Rep 41, 3745–3754. https://doi.org/10.1007/s11033-014-3239-x

Ayantunde, A.A., Asse, R., Said, M.Y., Fall, A., 2014. Transhumant pastoralism, sustainable management of natural resources and endemic ruminant livestock in the sub-humid zone of West Africa. Env. Dev Sustain 16, 1097–1117. https://doi.org/10.1007/s10668-014-9515-z

Ayantunde, A.A., Kango, M., Hiernaux, P., Udo, H.M.J., Tabo, R., 2007. Herders' Perceptions on Ruminant Livestock Breeds and Breeding Management in Southwestern of Niger. Hum Ecol 35, 139–149. https://doi.org/10.1007/s10745-006-9049-6

Barbato, M., Orozco-terWengel, P., Tapio, M., Bruford, M.W., 2015. SNeP: a tool to estimate trends in recent effective population size trajectories using genome-wide SNP data. Front. Genet. 6. https://doi.org/10.3389/fgene.2015.00109

Bayou, E., Haile, A., Gizaw, S., Mekasha, J., 2018. Definition of smallholder Sheko cattle keepers' breeding objectives through phenotypic ranking and choice experiments in Ethiopia. Afr. J. Agric. Res. 13, 389–402. https://doi.org/10.5897/AJAR2014.9119

Belemsaga, D.M.A., Lombo, Y., Thevenon, S., Sylla, S., 2005. Inventory analysis of West African cattle breeds. Makkar HPS Vilioen GJeds Appl. Gene-Based Technol. Improv. Anim. Prod. Health Dev. Ctries. Springer Neth. 167–173.

Blagna, S., Tellah, M., Mbaindingatoloum, M., Mopaté Logntene, Y., Boly, H., 2017. Insémination artificielle bovine par synchronisation des chaleurs au CRESTARND en milieu éleveur dans les cascades au Burkina Faso. J. Appl. Biosci. 110, 10819–10830.

Blench, R., 1999. Traditional livestovk breeds: geographical distribution and dynamics in relation to the ecology of West Africa (Working Paper). Overseas Development Institute, Portland House Stage Place London, SW1E 5DP,UK.

Bosso, N.A., 2006. Genetic improvement of livestock in tsetse infested area in West Africa (PhD). Wageningen University, The Netherlands.

Bosso, N.A., Corr, N., Nie, M., Fall, A., van der Waaij, E.H., van Arendonk, J.A.M., 2007. The N'Dama cattle genetic improvement programme: A review. Anim. Genet. Resour. Inf. 40, 65–69.

Bosso, N.A., van der Waaij, E.H., Kahi, A.K., van Arendonk, J.A.M., 2009. Genetic analysis of N'Dama cattle breed selection schemes. Livest. Res. Rural Dev. 21, 135.

Boushaba, N., Boujenan, J., Moazami-Goudarzi, K., Flori, L., Saïdi-Mehtar, N., Tabet-Aoul, T., Laloë, D., 2018. Genetic diversity and relationships among six local cattle populations in semi-arid areas assessed by a bovine medium-density single nucleotide polymorphism data. Animal. https://doi.org/10.1017/S1751731118001179

Boutrais, J., 2007. The Fulani and cattle breeds: crossbreeding and heritages strategies. Africa 77, 18–36.

Camara, Y., 2019. Analyse sociotechnique et organisationnelle du programme de sélection du bovin N'Dama au Sénégal. Université de Liège, Belgique.

Camara, Y., Moula, N., Sow, F., Sissoko, M.M., Antoine-Moussiaux, N., 2018. Analysing innovations among cattle smallholders to evaluate the adequacy of breeding programs. Animal 1–10. https://doi.org/10.1017/S1751731118001544

Camara, Y., Sissoko, M.M., Sall, M., Farnir, F., Antoine-Moussiaux, N., 2020. Programme de sélection du bovin N'Dama en Afrique de l'Ouest: cas du sénégal, du Mali et de la Gambie. Cah. Agric. 29. https://doi.org/10.1051/cagri/2020010

Camara, Y., Sow, F., Govoeyi, B., Sissoko, M.M., Antoine-Moussiaux, N., 2019. Stakeholders involvement in cattle-breeding program in developping countries: A Delphi survey. Livest. Sci. 228, 127–135. https://doi.org/10.1016/j.livsci.2019.08.014

Chang, C.C., Chow, C.C., Tellier, L.C., Vattikuti, S., Purcell, S.M., Lee, J.J., 2015. Second-generation PLINK: rising to the challenge of larger and richer datasets. GigaScience 4, 7.

Corbin, L.J., Liu, A.Y.H., Bishop, S.C., Woolliams, J.A., 2012. Estimation of historical effective population size using linkage disequilibria with marker data. J. Anim. Breed. Genet. 129, 257–270. https://doi.org/10.1111/j.1439-0388.2012.01003X

Curik, I., Ferenčaković, M., Sölkner, J., 2014. Inbreeding and runs of homozygosity: A possible solution to an old problem. Livest. Sci. 166, 23–34.

DAD-IS, 2019. FAO's Domestic Animal Diversity Information.

Decker, E.J., McKay, D.S., Rolf, M.M., Kim, JW., Alcala, M.M., Sonstegard, S.T., Hanotte, O., Götherström, A., Seabury, M.C., Praharani, L., Babar, E.M., Correia de Almeida Regitano, L., Yildiz, A.M., Heaton, P.M., Liu, W.-S., Lei, C.-Z., Reecy, M.J., Saif-Ur-Rehman, M., Schnabel, D.R., Taylor, F.J., 2014. Worldwide Patterns of Ancestry, Divergence, and Admixture in Domesticated Cattle. PLOS Genet. 10, e1004254.

Dempfle, L., Jaitner, J., 2000. Case study about the N'Dama breeding programme at the International Trypanotolerance Centre (ITC) in the Gambia (ICAR Technical Series No. No 3).

Deng, T., Liang, A., Liu, J., Hua, G., Ye, T., Liu, S., Campanile, G., Plastow, G., Zhang, C., Wang, Z., Salzano, A., Gasparrini, B., Cassandro, M., Riaz, H., Liang, X., Yang, L., 2019. Genom-Wide SNP Data Revealed the Extent of Linkage Disequilibrium, Persistence of Phase and Effective Population Size in Purebred and Crossbred Buffalo Populations. Front. Genet. 9. https://doi.org/10.3389/fgene.2018.00688

Dessie, T., Mwai, O., 2019. The story of cattle in Africa: Why diversity matters. International Livestock Research Institute, Rural Administration of the Republic of Korea and the African Union-InterAfrican Bureau for Animal Resources, Nairobie, Kenya.

Desta, T.T., Ayalew, W., Hegde, B.P., 2011. Breed and traits preferences of Sheko cattle keepers in southwestern Ethiopia. Trop. Anim. Health Prod. 43, 851–856. https://doi.org/10.1007/s11250-010-9772-2

Dossa, L.H., Vanvanhossou, F.U.S., 2016. The indigenous Somba cattle of the hilly Atacora region in North-West Benin: threatsand opportunities for its sustainable use. Trop. Anim. Health Prod. 48, 349–359. https://doi.org/10.1007/s11250-015-0958-5

Ducrocq, V., Laloe, D., Swaminathan, M., Rognon, X., Tixier-Boichard, M., Zerjal, T., 2018. Genomics for Ruminants in Developing Countries: From Principles to Practices. Front. Genet. 9. https://doi.org/10.3389/fgene.2018.00251

Duguma, G., 2010. Participatory definition of breeding objectives and implementation of community-based sheep breeding programs in Ethiopia (Doctoral Thesis). University of Natural Resources and Life Sciences, Vienna, Austria.

Duguma, G., Mirkena, T., Haile, A., Okeyo, A.M., Tibbo, M., Rischkowsky, B., Sölkner, J., Wurzinger, M., 2011. Identification of smallholder farmers and pastoralists' preferences for sheep breeding traits: choice model approach. Anim. Int. J. Anim. Biosci. 5, 1984–92. https://doi.org/10.1017/S1751731111001029

Edea, Z., Dadi, H., Kim, S.-W., Dessie, T., Lee, T., Kim, H., Kim, J.-J., Kim, K.-S., 2013. Genetic diversity, population structure and relationships in indigenous cattle populations of Ethiopia and Korean Hanwoo breeds using SNP markers. Front. Genet. 4. https://doi.org/10.3389/fgene.2013.00035

Ejlertsen, M., Poole, J., Marshall, K., 2013. Traditional breeding objectives and practices of goat, sheep and cattle smallholders in The Gambia and implications in relation to the design of breeding interventions. Trop. Anim. Health Prod. 45, 219–229. https://doi.org/10.1007/s11250-012-0194-1

Fall, A., Fadiga, M., Ayantunde, K., Marshall, K., Said, M., 2016. Sustainable management of endemic ruminant livestock of West Africa and their environment (ILRI Project Report). International Livestock Research Institute (ILRI), Nairobie, Kenya.

FAO, 2019a. Le devenir de l'élevage au Burkina Faso. Défis et opportunités face aux incertitudes (French). Rome, Italy.

FAO, 2019b. Africa Sustainable Livestock 2050 - Livestock sector development in Asia and sub-Saharan Africa – A comparison of sector growth and transformation. Rome. Rome.

FAO, 2016. The contributions of livestock species and breeds to ecosystem services, 24.

FAO, 2012. Phenotypic Characterization of Animals Genetics Resources (No. 11). Rome, Italy.

FAO, 2010a. Breeding Strategies for Sustainable Manage-ment of Animal Genetic Resources. (FAO Animal Produc- tion and Health Guidelines No. N°3). Rome, Italy.

FAO, 2010b. Progress Report of the FAO on Selected Activities Related to Agricultural Biodiversity. Avilable online at:

FAO, 2007. The state of the world's animal genetic resources for food and agriculture. FAO, Rome, Italy.

FAOSTAT, 2019. FAO statistical database (Available at http://www.fao.org/faostat/en/).

Ferenčaković, M., Hamzić, E., Gredler, B., Solberg, T.R., Klemetsdal, G., Curik, I., Sölkner, J., 2013a. Estimates of autozygosity derived from runs of homozygosity: empirical evidence from selected cattle populations. J. Anim. Breed. Genet. 130, 286–293.

Ferenčaković, M., Sölkner, J., Curik, I., 2013b. Estimating autozygosity from high-throughput information: effects of SNP density and genotyping errors. Genet. Sel. Evol. 45, 42.

Gamaniel, I.B., Egahi, J.O., Addass, P.A., 2019. Effect Year of Calving and Parity on the Productive and Performance of Holstein Friesan Cows in Vom Nigeria. Asian J. Res. Anim. Vet. Sci. 4, 1–8.

Gautier, M., Flori, L., Riebler, A., Jaffrézic, F., Laloé, D., Cut, I., Moazami-Goudarzi, K., Foulley, J.-L., 2009. A whole genome Bayesian scan for adaptive genetic divergence in West African cattle. BMC Genomics 10. https://doi.org/10.1186/l47l-2164-10-550

Getachew, T., Haile, A., Tibbo, M., Sharma, A.K., 2010. Herd management and breeding practices of sheep owners in a mixed crop-livestock and a pastoral system of Ethiopia. Afr. J. Agric. Res. 5, 685–691. https://doi.org/10.5897/AJAR10.392

Gizaw, S., Abebe, A., Bisrat, A., Zewdie, T., Tegegne, A., 2018. Defining smallholders' sheep breeding objectives using farmers trait preferences versus bio-economic modelling. Livest. Sci. 214, 120–128.

Gizaw, S., Getachew, T., Edea, Z., Mirkena, T., Duguma, G., Tibbo, M., Rischkowsky, B., Mwai, O., Dessie, T., Wurzinger, M., Sölkner, J., Haile, A., 2013. Characterization of indigenous breeding stretegies of the sheep farming communities of Ethiopia: A basis for designing community-based breeding programs. (Working Paper). ICARDA, Aleppo, Syria.

Goddard, M.E., 1998. Consensus and debate in the definition of breeding objectives. J. Dairy Sci. 81, 6–18.

Gowane, G.R., Kumar, A., Nimbkar, C., 2019. Challenges and opportunities to livestock breeding programmes in India. J. Anim. Breed. Genet. 136, 329–338. https://doi.org/10.1111/jbg.12391

Gréma, M., Traoré, A., Issa, M., Hamani, M., Abdou, M., Fernandez, I., Soudré, A., Alvarez, I., Sanou, M., Tamboura, H.H., Alhassane, Y., Goyache, F., 2017. Morphological assessment of Niger Kuri cattle using multivariate methods. South Afr. J. Anim. Sci. 47. https://doi.org/10.4314/sajas.v47i4.9

Gruber, B., Unmack, P.J., Berry, O.F., Georges, A., 2017. An R package to facilitate analysis of SNP data generated from reduced representation genome sequencing. Mol Ecol Res 18, 691–699. https://doi.org/10.1111/1755-0998.12745

Guangul, A.S., 2014. Design of community-based breeding programs for two idigenous goats breed in Ethiopia (Doctoral Thesis). University of Natural Resources and Life Sciences, Vienna, Austria.

Haile, A., Wurzinger, M., Mueller, J., Mirkena, T., Duguma, G., Mwai, O., Sölkner, J., Rischkowsky, B., 2011. Guidelines for Setting up community-based sheep Breeding Programs in Ethiopia. ICARDA-tools and Guidelines No.1, Aleppo, Syria, ICARDA.

Haile, A., Wurzinger, M., Mueller, J.P., Mirkena, T., Duguma, G., Rekik, M., Mwacharo, J., Mwai, O., Sölkner, J., Rischkowsky, B., 2018. Guidelines for Setting Up community-based small ruminants breeding programs in Ethiopia. ICARDA-tools and Guidelines No.1, Beirut, Lebanon: ICARDA.

Hampshire, K., 2006. Flexibility in Domestic Organization and Seasonal Migration Among the Fulani of Northern Burkina Faso. Africa 76, 402–426. https://doi.org/10.3366/afr.2006.0044

Hanotte, O., Tawah, C.L., Bradley, D.G., Okomo, M., Verjee, Y., Ochieng, J., Rege, J.E.O., 2009. Geographic distribution and frequency of a taurine Bos taurus and an indicine Bos indicus Y specific allele amongst sub-saharan African cattle breeds. Mol. Ecol. 9, 387–396.

Hayes, B.J., Visscher, P.M., McPartlan, H.C., Goddard, M.E., 2003. Novel Multilocus Measure of Linkage Disequilibrium to Estimate Past EffectivePopulation Size. Genome Res. 13, 635–643. https://doi.org/10.1101/gr.387103

Henry, S., Piché, V., Ouédraogo, D., Lambin, F.E., 2004. Descriptive Analysis of the Individual Migratory Pathways According to Environment Typologies. Popul. Environ. 25, 397–422.

Heringstad, B., Klemetsdal, G., Ruane, J., 2000. Selection for mastitis resistance in dairy cattle: a review with focus on the sistuation in the Nordic countries. Livest. Prod. Sci. 64, 95–106.

Houessou, S.O., Dossa, L.H., Diogo, R.V.C., Houinato, M., Buerkert, A., Schlecht, E., 2019. Change and continuity in traditional cattle farming systems of West African Coast countries: A case study from Benin. Agric. Syst. 168, 112–122. https://doi.org/10.1016/j.agsy.2018.11.003

Ibeagha-Awemu, M.E., Jann, C.O., Weimann, C., Erhardt, G., 2004. Genetic diversity, introgression and relationships among West/Central African cattle breeds. Genet. Sel. Evol. 36, 673–690. https://doi.org/10.1051/gse:2004024

Iniguez, I., 1998. community breeding programs for small ruminants in the Andean region., in: Procedings of the 6th Congress on Genetics Applied to Livestock Production. Armidale, NSW, Australia, pp. 249–256.

INSD (Institut National de la Statistique et de la Démographie). Indicateurs Démographiques du Burkina Faso. Available online at www.isnd.bf

Jabbar, M.A., Swallow, G.D.M. d'Ieteren, Busari, A.A., 1998. Farmer preferences and market values of cattle breeds of West and Central Africa. J. Sustain. Agric. 12, 21–47.

Jaitner, J., Corr, N., Dempfle, L., 2003. Ownership pattern and management practices of cattle herds in The Gambia: implication for a breeding programme. Trop. Anim. Health Prod. 35, 179–187.

Janssen-Tapken, U., 2009. Developing optimized cattle breeding schemes based on thedemands and opportunities of poor livestock keepers in Eastern Africa with a special focus on Trypanosomiasis (Doctoral Thesis). Swiss Federal Institute of Technology, Zurich.

Jemaa, B.S., Rahal, O., Gaouar, S.B.S., Mastrangelo, S., Boussaha, M., Ciani, E., 2018. Genomic characterization of Algerian Guelmoise cattle and their genetic relationship with other North African populations inferred from SNP genotyping arrays. Livest. Sci. 217, 19–25. https://doi.org/10.1016/j.livsci.2018.09.009

Jombart, T., 2008. a R package for the multivariate analysis of genetic markers. Bioinformatics 24, 1403–1045.

Jombart T., Collins C., 2015. A tutorial for Discriminant Analysis of Principal Components (DAPC) using adegenet 2.0.0. Imperial College London, MRC Centre for Outbreak Analysis and Modelling.

Kahi, A.K., Rewe, T.O., Kosgey, I.S., 2005. Sustainable communitybased organizations for the genetic improvement of livestock in developing countries. Outlook Agric. 34, 261–270.

Kamuanga, M., Tano, K., Pokou, K., Jabbar, M.A., Swallow, B., d'Ieteren, G., 2001. Faremres' preferences of cattle breeds, their market values and prospects for improvement in West Africa: A summary review, in: K R Sones (Ed): Proceeding of the 25th Meeting of the International Scientific Council for Trypanosomiasis Research and Control (ISCTRC). Stockwatch Ltd, Nairobi, Kenya, Mombasa, Kenya, September 1999, pp. 271–298.

Kassa, S.K., Dayo, G.K.C., Yapi-Gnaore, C.V., Sylla, S., Konkobo, M., Issaka, Y.A.K., 2019. Genetic Diversity of Benin Cattle Populations Using Microsatellite Markers. Int. J. Anim. Sci. Technol. 3, 7–19. https://doi.org/10.11648/j.ijast.20190301.12

Kassie, G.T., Abdulai, A., Wollny, C., 2009. Valuing traits of indigenous cows in Central Ethiopia. Journal of Agricultural Economics. J. Agric. Econ. 60, 386–401. https://doi.org/10.1111/j.1477-9552.2008.00191.x

Kaumbata, W., Banda, L., Mészáros, G., Gondwe, T., Woodward-Greene, M.J., Rosen, D.B., Van Tassell, P.C., Sölkner, J., Wurzinger, M., 2020. Tangible and intangible benefits of local goats rearing in smallholders farms in Malawi. Small Rumin. Res. 187. https://doi.org/10.1016/j.smallrumres.2020106095

Kim, K., Kwon, T., Dessie, T., Yoo, D., Mwai, A.O., Jang, J., Sung, S., Lee, S., Salim, B., Jung, J., Jeong, H., Tarekegn, G.M., Tijjani, A., Lim, D., Cho, S., Oh, S.J., Le, H.-K., Kim, J., Jeong, C., Kemp, S., Hanotte, O., Kim, H., 2020. The mosaic genome of indigenous African cattle as a unique genetic resource for African pastoralism. Nat. Genet. 52, 1099–1110. https://doi.org/10.1038/s41588-020-0694-2

Kinkpé, A.T., Diogo, R.V.C., Kpadé, P.C., Yabi, A.J., Dossa, L.H., 2019. The role of cattle attributes in buyers' choices in Benin. Afr. J. Agric. Resour. Econ. 14, 56–71.

Köhler-Rollefson, I., 2000. Management of Animal Genetic Diversity at Community Level. GTZ, Eschborn.

Kosgey, I.S., Baker, R.L., Udo, H.M.J., van Arendonk, J.A.M., 2006. Successes and failures of small ruminant breeding programmes in the tropics: a review. Small Rumin. Res. 61, 13–28.

Kosgey, I.S., Okeyo, A.M., 2007. Genetic improvement of small ruminants in low-input, smallholder production systems: Technical and infrastructural issues. Small Rumin. Res. 70, 76–88.

Leroy, G., Baumung, R., Notter, D., Verrier, E., Wurzinger, M., Scherf, B., 2017. Stakeholder involvement and the management of animal genetic resources across the world. Livest. Sci. 198, 120–128. https://doi.org/10.1016/j.livesci.2017.02.018

Lobo, R.N.B., 2019. Opportunities for investment into small ruminant breeding programmes in Brazil. J. Anim. Breed. Genet. 136, 313–318. https://doi.org/10.1111/jbg.12396

Madilindi, M.A., Banga, C.B., Bhebhe, E., Sanarana, Y.P., Nxumalo, K.S., Taela, M.G., Magagula, S.B., Mapholi, N.O., 2019a. Genetic diversity and relationships among three Southern African Nguni cattle populations. Trop. Anim. Health Prod. https://doi.org/10.1007/s11250-019-02066-y

Madilindi, M.A., Banga, C.B., Bhebhe, E., Sanarana, Y.P., Nxumalo, K.S., Taela, M.G., Mapholi, N.O., 2019b. Genetic differentiation and population structure of four Mozambican indigenous cattle populations. Livest. Res. Rural Dev. 31.

Majekodunmi, A.O., Dongkun, C., Langs, T., Shaw, A.P.M., Welburn, S.C., 2017. Shifting livelihood stratgies in northern Nigeria-extensified production and livelihood diversification amongst Fumani pastoralists. Pastor. Res. Policy Pract. 7. https://doi.org/10.1186/s13570-017-0091-3

Makanjuola, B.O., Miglior, F., Abdalla, E.A., Maltecca, C., Schenkel, F.S., Baes, C.F., 2020. Effect of genomic selection on rate of inbreeding and coancestry and effective population size of Holstein and Jersey cattle populations. J. Dairy Sci. 103, 5183–5199. https://doi.org/10.3168/jds.2019-18013

Makina, O.S., Muchadeyi, C.F., van Marle-Köster, E., MacNeil, D.M., Maiwashe, A., 2014. Genetic diversity and population structure among six cattle breeds in South Africa using a whole genome SNP panel. Front. Genet. 5. https://doi.org/10.3389/fgene.2014.00333

Mapiye, C., Chimonyo, M., Raats, J.G., Mapekula, M., 2009. Opportunities for improving Nguni cattle production in smallholder farming systems of South Africa. Livest. Sci. 124, 196–204. https://doi.org/10.1016/j.livsci.2009.01.013

Marshall, K., Tebug, S., Salmon, G.R., Tapio, M., Juga, J., Missou, A., 2017. Improving dairy cattle productivity in Senegal. ILRI Policy Brief 22.

Mastrangelo, S., Tolone, M., Di Gerlando, R., Fontanesi, L., Sardina, M.T., Portolano, B., 2016. Genomic inbreeding estimation in small populations: evaluation of runs of homozygosity in three local dairy cattle breeds. Animal 10, 746–754. https://doi.org/10.101/S1751731115002943

Mhlanga, F.N., 2002. Community-based Management of Animal Genetic Resources: A Participatory Framework Approach. Department of Animal Sciences, University of Zimbabwé, Harare.

Mirkena, T., 2010. Identifying breeding objectives of smallholders/pastoralists and optimizing community-based breeding programs for adapted sheep breeds in Ethiopia (Doctoral Thesis). University of Natural Resources and Life Sciences, Vienna, Austria.

Mirkena, T., Duguma, G., Willam, A., Wurzinger, M., Haile, A., Rischkowsky, B., Okeyo, A.M., Tibbo, M., Sölkner, J., 2012. Community-based alternative breeding plans for indigenous sheep breeds in four agro-ecological zones of Ethiopia. J. Anim. Breed. Genet. 129, 244–253. https://doi.org/10.1111/j.1439-0388.2011.00970x

Molina-Flores, B., Manzano-Baena, P., Coulibaly, M.D., 2020. The role of livestock in food security, poverty reduction and wealth creation in West Africa. FAO, Accra.

Mopaté, L.Y., 2015. Caractéristiques, menaces et nécessité de conservation in situ du taurin Baoulé dans les savanes du Sud-Ouest du Burkina Faso. J. Appl. Biosci. 93, 8713 – 8726.

Mopaté, Y.L., Kamuanga, M.J.B., Hamadou, S., Kaboré-Zoungrana, C.-Y., 2014. Evaluation des pratiques paysannes de conservation in situ du taurine Baoulé au Sud-Ouest du Burkina Faso. Anim. Genet. Resour. 54, 171–178. https://doi.org/10.1017/S2078633614000022

Moussa, M.M.A., Issa, M., Traoré, A., Gréma, M., Hamani, M., Fernandez, I., Soudré, A., Alvarez, I., Sanou, M., Tamboura, H.H., Alhassane, Y., Goyache, F., 2017. Morphological assessment of the Zebu Bororo (Wodaabé) cattle of Niger in the West African zebu framework. Arch Anim Breed 60, 363–371. https://doi.org/10.5194/aab-60-363-2017

MRA (Ministère des Ressources Animales), 2014. Annuaire des statistiques d'élevage 2014. Burkina Faso.

Mueller, J.P., Rischkowsky, B., Haile, A., Philipsson, J., Mwai, O., Besbes, B., Valle Zarate, A., Tibbo, M., Mirkena, T., Duguma, G., Sölkner, J., Wurzinger, M., 2015. Community-based livestock breeding programs: essentials and examples. J. Anim. Breed. Genet. 132, 155–168. https://doi.org/10.1111/jbg.12136

Mwai, O., Hanotte, O., Kwon, Y.-J., Cho, S., 2015. Africa Indigenous Cattle: Unique Resources in Rapidly Changing World. Asian Australas. J. Anim. Sci. 28, 911–921.

Nandolo, W., Mészáros, G., Banda, L.J., Gondwe, N.T., Lamuno, D., Mulindwa, H.A., Nakimbugwe, N.H., Wurzinger, M., Utsunomiya, T.Y., Woodward-Greene, M.J., Liu, M., Liu, G., Van Tassell, P.C., Curik, I., Rosen, D.B., Sölkner, J., 2019. Timing and extent of inbreeding in African goats. Front. Genet. 10, 537. https://doi.org/10.3389/fgene.2019.00537

Nandolo, W., Wurzinger, M., Gabor, M., Van Tassell, C., Gondwe, T., Mulindwa, H., Lamuno, D., Sölkner, J., 2016. Identification of breeding objectives in community based goat breeding programmes in Malawi.

Ndiaye, N.P., Sow, A., Ndiaye, S., Sawadogo, G.J., Sembene, M., 2015. Bottleneck and molecular variance analyses in Senegalese local cattle breeds using microsatellite markers. Res. Opin. Anim. Vet. Sci. 5, 158–164.

Ndumu, D.B., Baumung, R., Wurzinger, M., Drucker, A.G., Okeyo, A.M., Semambo, D., Sölkner, J., 2008. Performance and fitness traits versus phenotypic appearance in the African Ankole Longhorn cattle: A novel approach to identify selection criteria for indigenous breeds. Livest. Sci. 13, 234–242.

Nei, M., Li, W.H., 1973. Linkage disequilibrium in subdivided populations. Genetics 75, 213–219.

Ngono, E.P.J., Lassila, L., Missohou, A., Marshall, K., Tapio, M., Tebug, S.F., Juga, J., 2018. Milk production traits among indigenous and crossbred dairy cattle in Senegal. Afr. J. Food Agric. Nutr. Dev. 18, 13572–13587.

Orozco-terWengel, P., Barbato, M., Nicolazzi, E., Biscarini, F., Milanesi, M., Davies, W., Williams, D., Stella, A., Ajmone-Marsan, P., Bruford, M.W., 2015. Revisiting demographic processes in cattle with genome-wide population genetic analysis. Front. Genet. 6. https://doi.org/10.3389/fgene.2015.00191

Ouédraogo, D., Soudré, A., Oudéraogo-Koné, S., Yougbaré, B., Zoma, B.L., Tapsoba, S.A.R., Mészáros, G., Burger, P., Khayatzadeh, N., Wurzinger, M., Traoré, A., Okeyo, A.M., Sölkner, J., 2020a. Selection of breeding bulls in community-based cattle breeding programs in Burkina Faso. Bull. Anim. Health Prod. Afr. 68, 103–111.

Ouédraogo, D., Soudré, A., Ouédraogo-Koné, S., Zoma, B.L., Yougbaré, B., Khayatzadeh, N., Burger, P.A., Mészáros, G., Traoré, A., Mwai, A.O., Wurzinger, M., Sölkner, J., 2020b. Breeding objectives and practices in three local cattle breed production systems in Burkina Faso with implication for the design of breeding programs. Livest. Sci. 232. https://doi.org/10.1016/j.livsci.2019.103910

Ouma, E., Abdulai, A., Druckers, A., 2007. Measuring hetergenous preferences for cattle traits among cattle-keeping households in East Africa. Am. J. Agric. Econ. 89, 1005–1019. https://doi.org/10.1111/j.1467-8276.2007.01022.x

Paré, S., Söderberg, U., Sandewall, M., Oubda, J.M., 2008. Land use analysis from spatial and field data capture in southern Burkina Faso, West Africa. Agric. Ecosyst. Environmeny 127, 2777–285. https://doi.org/10.1016/j.agee.2008.04.009

Parish, J.A., Karisch, B.B., 2013. Estimating Cattle Age Using Dentition. Mississippi State University Extension Service, cooperating with US., p. 7.

PérezO’Brien, A.M., Mészáros, G., Utsunomiya, T.Y., Sonstegard, S.T., Garcia, F.F., VanTassell, C.P., Carvalheiro, R., daSilva, M.V., Sölkner, J., 2014. Linkage disequilibrium levels in Bos indicus and Bos taurus cattle using medium and high density SNP chip data and different minor allele frequency distributions. Livest. Sci. 166, 121–132. https://doi.org/10.1016/j.livsci.2014.05.00

Purcell, S., Neale, B., Todd-Brown, K., Thomas, L., Ferreira, M.A.R., Bender, D., Maller, J., Sklar, P., de Bakker, P.I.W., Daly, M.J., et, al., 2007. PLINK: A Tool Set for Whole-Genome Association and Population-Based Linkage Analyses. Am. J. Hum. Genet. 81, 559–575. https://doi.org/10.1086/519795

Purfield, C.D., Berry, P.D., McParland, C., Bradley, D., 2012. Run of homozygosity and population history in cattle. BMC Genet. 13.

Rahimi, J., Mutua, J.Y., Notenbaert, A.M.O., Dieng, D., Butterbach-Bahl, K., 2020. Will dairy cattle production in West Africa be challenged by heat stress in the future? Clim. Change 161, 665–685. https://doi.org/10.1007/s10584-020-02733-2

Rege, J.E.O., Tawah, C.L., 1999. The state of African cattle genetic resources II. Geographical distribution, characteristics and uses of present-day breeds and strains. Anim. Genet. Resour. Inf. 25, 1–25.

Rege, J.E.O., Yapi-Gnaore, C.V., Tawah, C.L., 1996. The indigenous domestic ruminant genetic resources of Africa, in: Proceedings 2nd Africa Conference on Animal Agriculture. Pretoria, South Africa, pp. 57–75.

Rege, J.R.O., 1994. Shorton Cattle of West and Central Africa. IV. Productions Characteristics. World Anim. Rev. 78, 33–43.

Renaudeau, D., Collin, A., Yahav, S., de Basilio, V., Gourdine, L.J., Collier, R.J., 2012. Adaptation to hot climate and strategies to alleviate heat stress in livestock production. Animal 6, 707–728. https://doi.org/10.1017/S1751731111002448

Rewe, T.O., Herold, P., Kahi, A.K., Valle Zarate, A., 2009. Breeding indigenous cattle genetic resources for beef production in Sub-Saharan Africa. Agriculture 38, 317–326.

Roessler, R., 2019. Selection Decisions and Trait Preferences for Local and Imported Cattle and Sheep Breeds in Peri-/Urban Livestock Production Ssystems in Ouagadougou, Burkina Faso. Animals 9. https://doi.org/10.3390/ani905207

Roessler, R., Mpouam, S.E., Schlecht, E., 2019. Genetic and nongenetic factors affecting on-farm performance of peri-urban dairy cattle in west Africa. J. Dairy Sci. 102, 2353–2364. https://doi.org/10.3168/jds.2018-15358

Saleh, M.K., Atala, T.K., Omokore, D.F., Ahmed, B., Ali, F.S., Kajang, G.Y., 2016. Performance of Improved Dairy Cattle Technologies Among Farmers in Nothern Nigeria. J. Agric. Ext. 20.

Santoze, A., Gicheha, M., 2019. The Status of Cattle Genetic Resources in West Africa: A Review. Adv. Anim. Vet. Sci. 7, 112–121. https://doi.org/10.17582/journal.aavs/2019/7.2.112.121

Saravanan, K.A., Panigrahi, M., Kumar, H., Bhushan, B., 2019. Advanced software programs for the analysis of genetic diversity in livestock genomics: a mini review. Biol. Rythm Res. https://doi.org/10.1080/09291016.2019.1642650

Scheper, C., Bohlouli, M., Brügemann, K., Weimann, C., Vanvanhossou, F.U.S., König, S., Dossa, L.H., 2020. The role of agro-ecological factors and transboundary transhumance in shaping the genetic diversity in four indigigenous cattle populations of Benin. J. Anim. Breed. Genet. 00, 1–19.

Silbermayr, K., Li, F., Soudré, A., Müller, S., Sölkner, J., 2013. A Novel qPCR Assay for the Detection of African Animal Trypanosomosis in Trypanotolerant and Trypanosusceptible Cattle Breeds. PLoS Negl. Trop. Dis. 7, e2345.

Sokouri, D.P., Loukou, N.E., Yapi-Gnaoré, C.V., Mondeil, F., Gangbe, F., 2007. Caractérisation phénotypique des bovins à viande (Bos taurus et Bos indicus) au Centre (Bouaké), Nord (Korhogo) de la Côte d'Ivoire. Anim. Genet. Resouces Inf. 40. https://doi.org/10.1017/S1014233900002182

Sölkner, J., Grausgruber, H., Okeyo, A.M., Ruckenbauer, P., Wurzinger, M., 2008. Breeding objectives and the relative importance of traits in plant and animal breeding: a comparative review. Euphytica 161, 273–282.

Sölkner, J., Nakimbugwe, H., Valle Zarate, A., 1998. Analysis of Determinants for Success and Failure of Village Breeding Programmes, in: Procedings of the 6th Congress on Genetics Applied to Livestock Production. Armidale, NSW, Australia, pp. 273–280.

Soro, B., Sokouri, D.P., Dayo, G.K., N'Guetta, A.S.P., Yapi-Gnaoré, C.V., 2015. Caractérisation des bovins de races Baoulé dans "le pays Lobi" de Côte d'Ivoire: rôles socio-économiques, mode d'élevage et contraintes de production. Tropicultura 33, 11–124.

Soudré, A., 2011. Trypanosomosis, genetic diversity and admixture in cattle breed of Burkina Faso (Doctoral Thesis). University of Natural Resources and Life Sciences, Vienna, Austria.

Soudré, A., Gréma, M., Tapsoba, S.A.R., Sanou, M., Traoré, A., Tamboura, H.H., 2018. Introduction of Exotic Breeds in Extensive Livestock Farming System of Burkina Faso: Assessment and Prospects. Int. J. Adv. Res. 6, 658–668. https://doi.org/10.21474/IJAR01/6715

Soudré, A., Gréma, M., Tapsoba, S.A.R., Traoré, A., Oudéraogo-Koné, S., Wurzinger, M., Müller, S., Hanotte, O., Ouédraogo, A.G., Sölkner, J., 2019. Is the introgression of Lobi/Baoulé cattle by zebuine genes in Burkina Faso Lobi cattle threatened? Afr. J. Biotechnol. 18, 77–85. https://doi.org/10.5897/AJB2018.16467

Soudré, A., Ouédraogo-Koné, S., Wurzinger, M., Müller, S., Hanotte, O., Ouédraogo, A.G., Sölkner, J., 2013. Trypanosomosis: a priority disease in tsetse-challenged areas of Burkina Faso. Trop. Anim. Health Prod. 45, 497–503. https://doi.org/10.1007/s11250-012-0248-4

Steglich, M., Peters, K.J., 2002. Ago-pastoralists' trait preference in N'Dama cattle: Participatory methods to assess breeding objectives. Presented at the 7th World Congress on Genetics Applied to Livestock Production, Montpellier, France, p. Communication N° 25-04.

Szmatola, T., Gurgul, A., Ropka-Molik, K., Jasielczuk, I., Zabek, T., Bugno-Poniewierska, M., 2016. Characteristics of runs of homozygosity in selected cattle breeds maintained in Poland. Livest. Prod. Sci. 188, 72–80. https://doi.org/10.1016/j.livsci.2016.04.006

Tadesse, D., Ayalew, W., Hedge, B.P., 2005. Survey of traditional cattle production systems and preferred cattle functions in North and South Wollo Zones, Ethiopia. Ethiop. Vet. J. 9, 91–108.

Tamboura, H.H., Gnanda, B.I., Kaboré, A., Traoré, A., 2008. Bilan des acquis du programme d'amélioration génétique mis en place dans le cadre du Projet de Soutien à la Diffusion du Zébu Azawak (PSDZA) phase II. INERA, Ouagadougou, Burkina Faso.

Tano, K., 1998. Genetic preferences of smallholders and trypanotolerant cattle in southern Burkina Faso (PhD). Univesity of Manitoba, Canada.

Tano, K., Kamuanga, M., Faminow, M.D., Swallow, B., 2003. Using conjoint analysis to estimate farmer's preferences for cattle traits in West Africa. Ecol. Econ. 45, 393–407.

The World Bank, 2017. Burkina Faso - Livestock Sector Development Support Project (P159476) (No. PAD2313). World Bank Group, Washington DC, USA.

Thébaud, B., Corniaux, C., François, A., Powell, A., 2018. Transhumance and livestock mobility in West Africa: 10 key findings on livestock mobility in West Africa.

Tijjani, A., Utsunomiya, T.Y., Ezkwe, G.A., Nashiru, O., Hanotte, O., 2019. Genome Sequence Analysis Reveals Selection Signatures in Endangered Trypanotolerant West Africa Muturu Cattle. Front. Genet. https://doi.org/10.3389/fgene.2019.00442

Traoré, A., Koudandé, D.O., Fernandez, I., Soudré, A., Granda, V., Alvarez, I., Diarra, S., Diarra, F., Kaboré, A., Sanou, M., Tamboura, H.H., Goyache, F., 2015. Geographical assessment of body measurements and qualitative traits in West African cattle. Trop. Anim. Health Prod. 47, 1505–1513. https://doi.org/10.1007/s11250-015-0891-7

Traoré, S.A., Markemann, A., Reiber, C., Piepho, H.P., Valle Zarate, A., 2017. Production objectives, traits and breeds preferences of farmers keeping N'Dama, Fulani Zebu and crossbreed cattle and implication for breeding programs. Animal 11, 687–695. https://doi.org/10.1017/S1751731116002196

Umar, D.S.B., Nwagu, B.I., Umar, U.A., Rufina, O.O., Saleh, I., Onotu, S.I., Ugwu, L., 2020. On-station Performance Evaluation of Indigenous Breeds of Cattle for Dairy Production Systems in Nigeria. Asian J. Res. Agric. For. 5, 30–38.

Valerio, V.C., Walther, O.J., Eilittä, M., Cissé, B., Muneepeerakul, R., Kiker, G.A., 2020. Network analysis of regional livestock trade in West Africa. PLOS ONE 15. https://doi.org/10.1371/journal.pone.0232681

Valle Zarate, A., Makermann, A., 2010. Community-based breeding programmes incorporating local breeds: Co cept, research results and implementation strategy on pigs in Northern Vietnam, in: Proceedings of the 9th World Congress on Genetics Applied to Livestock Pro-Duction. Leipzig, Germany, p. 845.

Wurzinger, M., Ndumu, D., Baumung, B., Druckers, A., Okeyo, M., Semambo, D.K., Byamungu, N., Sölkner, J., 2006. Comparison of production systems and selection criteria of Ankole cattle by breeders in Burundi, Rwanda, Tanzania and Uganda. Trop. Anim. Health Prod. 38, 571–581.

Wurzinger, M., Sölkner, J., Iniguez, L., 2011. Important aspects and limitations in considering community-based breeding programs for low-input smallholder livestock systems. Small Rumin. Res. 98, 170–175. https://doi.org/10.1016/j.smallrumres.2011.03.035

Yakubu, A., Dahloum, L., Gimba, E.G., 2019. Smallholder cattle farmers' breeding practices and trait preferences in a tropical Guinea savanna agro-ecological zone. Trop. Anim. Health Prod. https://doi.org/10.1007/s11250-019-01836-y

Yapi-Gnaoré, C.V., 2000. The open nucleus breeding programme of the Djallonke sheep in Côte D'Ivoire, in: Galal, S., Boyazoglu, J., Hammond, K. (Eds.). Presented at the Proceedings of the Workshop on Developing Breeding Strategies for Lower Input Animal Production Environments, ICAR Technical Series, Bella, Italy, 22-25 September 1999, pp. 283–292.

Yapi-Gnaoré, C.V., BA, O., Ouattara, Z., 1996. Revue de la situation des races d'animaux domestiques de Côte d'Ivoire. Anim. Genet. Resour. Inf. 19, 99–118.

Zampaligré, N., Dossa, L.H., Schlecht, E., 2014. Climate change and variability: perception and adaptation strategies of pastoralists and agro-pastoralists across different zones of Burkina faso. Reg. Environ. Change 14, 769–783. https://doi.org/10.1007/s10113-013-0532-5

Zander, K.K., Drucker, A.G., 2008. Conserving what is important: using choice model scenarios to value local cattle breeds in East Africa. Ecol. Econ. 68, 34–45.

Zavarez, B.L., Utsunomiya, T.Y., Camo, S.A., Neves, R.H.H., Carvalheiro, R., Ferenčaković, M., Pérez O'Brien, M.A., Curik, I., Cole, B.J., Van Tassell, P.C., da Silva, B.G.M., Sonstegard, S.T., Sölkner, J., Garcia, F.J., 2015. Assessment of autozygosity in Nellore cows (Bos indicus) through high-density SNP genptypes. Front. Genet. 6. https://doi.org/10.3389/fgene.2015.00005

Zewdu, A., Alemayehu, K., Wondifraw, Z., 2018. Breeding Practices and Farmers Traits Preferences on Indigenous Dairy Cattle Production in East Gojjam Zone, Ethiopia. Asian J. Agric. Food Sci. 06.

Zewdu, W., Ayalew, W., Sölkner, J., 2006. Breeding Scheme Based on Analysis of Community Breeding Objectives for Cattle in North-western Ethiopia. Ethiop. J. Anim. Prod. 6, 53–66.

Zhang, J., Nie, C., Li, X., Ning, Z., Chen, Y., Jia, Y., Han, J., Wang, L., Lv, X., Yang, W., Qu, L., 2020. Genome-Wide Population Genetic Analysis of Commercial, Indigenous, Game, and Wild Chickens Using 600K SNP Microarray Data. Front. Genet. 11. https://doi.org/10.3389/fgene.2020.543294

Zhang, L., Orloff, S.M., Reber, S., Li, S., Zhao, Y., Eng, C., 2013. cgaTOH: Extended Approach for Identifying Tracts of Homozygosity. PLoS ONE 8, e57772. https://doi.org/10.1371/journal.pone.0057772

Zongo, M., Boly, H., Sawadogo, L., Pitala, W., Sousa, M.N., Beckers, J.F., Leroy, P.L., 2001. Insémination artificielle des vaches Zébu 'Azawak' et taurins 'Gurunsi' au Burkina Faso. Tropicultura 19, 75–78.

Appendices

Appendix

Appendix 1: Questionnaire for baseline survey

1: Questionnaire for baseline survey

BASELINE SURVEY

Date: …. /…. /2017 Fiche N°: Name of interviewer: _______________

I. FARMER'S IDENTIFICATION AND HOUSEHOLD CHARACTERISTICS

Commune : ________ Village : ___________ Geographic coordinates : _________________

1.1. Name and Surname of farmer: _________________________ 1.2. Phone: ________________

1.3. Sex: ___________ *(1=Male, 2=Female) 1.4.* Age: _______ *Years*

1.5. Ethnic group's: ___________ *(1=Lobi, 2=Birifore 3=Djan, 4=Dagari, 5=Peulh, 6=Mossi, 7=Other (Specify))* ……………………………………………………………………………………………

1.6. Education bacground: ______ *(1=Iliteracy, 2=Literacy)*
1.7. If Literacy, Number of years in school _______ *Years*

1.8. Status______ *(1=Native, 2=Migrant)*

1.9. Household composition's: Men: _____ *(≥18years)* - Women: _______ *(≥18years)*
Sons *(0 – 17years)* : ______ Daughters *(0 – 17years)* : ______

1.20. Do you employ paid labourers ? _______ (*1=Yes, 2=No)*
1.21. If yes, Seasonal _______ Permanent_______
1.22. Payment______________________ (If in nature, give value in cash)

1.9. Family main source of income: _______ (*1=Crop, 2=Livestock, 3=Fishing, 4-Trade, 5=Gold washing, 6=State employee, 7= Others (Specify))* ……………………………………………………………

1.20. How did you acquire your cattle nucleus ? _______ *(1=Heritage, 2=Gift, 3=Purchase, 4=Other (Specify))*

II. HERD COMPOSITION, STRUCTURE AND MANAGEMENT

2.1. Livestock species and their numbers

Species	**Number**

Cattle	
Ploughing cattle	
Sheep	
Goats	
Pigs	
Donkeys	
Poultry	
Other (Specify)	

2.2. Current cattle breeds

Breed	**Number**	**Bulls**	**Cows**	**Young bulls (≤3years)**	**Heifers**	**Claves (≤1years)**	
						Male	Female
Baoulé Cattle							
Zebu							
Crossbreed							
Other							

2.3. Major objectives of cattle production (Rank on their importance)

Use	**Tick**	**Rank**
Cash income		
Meat (Home consumption)		
Milk (Home consumption)		
Saving		
Wealth status		

Social		
Other (specify)		

2.4. Which species of livestock are more important for your lievlihood (rank)

Species	**Tick**	**Rank**
Cattle		
Sheep		
Goat		
Poultry		
Other (Specify)		

2.5. Animal flow in the herd

Specie	Inflow *(1=Birth, 2=Purchase, 3=Gift, 4=Other (Specify))*	Outflow (1=Death, 2=Sale, 3=Gift, 4=Sacrifices, 5=Home consumption, 6=Other (Specify))
Cattle		
Ploughing cattle		
Sheep		
Goat		
Pig		

2.6. Who is the shepher ? _______*1 = salaried, 2= members of family ; 3= nothing*

III. REPRODUCTIVE PERFORMANCES

3.1. Reproductive performances of the current breeds

Breeds	**Average age of 1st mating**		**Average age of 1st calving**	**Average interval calving**	**Average reproductive age**	**Number of calves / female life**
	Male	**Female**				
Baoulé						
Zebu						

Crossbreed						

3.2. Do you fix age at first mating for the females? _______ *(1=Yes, 2=No)*

3.3. Do you fix age at first mating for the males? _______ *(1=Yes, 2=No)*

3.4. Months where frequent calving are happening.

Month	**Tick**	**Rank**

IV. MATING AND MALE SELECTION FOR REPRODUCTION

4.1. Do you have your own bull? ______ *(1=Yes, 2=No)*

4.2. If **No**, where do you get bull for mating? _______ *(1=Borrowing, 2=By rent, 3=Other (specify))* ………………………………………………………………………………

4.3. If **Yes**, how many bulls do you have? _______

4.4. If you have more than one, why do you need to keep more than one? .... …………………………………………………………………………………………………

4.5. How your bull gives mating service? ______ *(1=My herd only, 2=My herd and neighbors, 3=Rent out, 4=No fixed)*

4.6. Is there special management for breeding bull? ______ *(1=Yes, 2=No)*

4.7. If **Yes**, what kind of management? ....

4.8. What is your purpose of keeping bull? ______ *(1=Mating, 2=Socio-cultural, 3=Fattening, 4=Other (Specify)*……………………………………………………………………………………………….

4.9. How long the same bull give service in herd? ______ Years

4.10. How mating is practice in your herd ? ______ *(1=Mixing bull with cows, introducing bull with fixed time, 4=Other (Specify))* ……………………………………………………………………………….

4.11. Do you practice control mating ? ______ (1= Yes, 2= No)

4.12. If **Yes**, how ? ______ *(1=Introduction of bull at fixed time, 2= Castrate unwanted bulls, 4= Other to specify) ………………………………………………………………………*

4.13. If **No**, why ? ________ *(1=Cattle graze together, 2=Lack of bulls, 3=Lack of awareness, 4=Other (specify)) …………………………………………………………………………………………………….*

4.14. Where do you get replacement bull ? ________ *(1=From young bulls of my own herd, 2=From young bulls of other herd, 3=Purchased from market, 4=Other (Specify))*………….…………………………….

4.15. Do you select best cows as parents of the next generation with in your cattle ? ______ *(1=Yes, 2=No)*

4.16. If **Yes**, what are your selectioon criteria for cows ?

Criteria	**Tick**	**Rank**
Size / appearance		
Color		
Horns		
Calves growth		
Calves survival		
Birth frequency		
Milk yield		
Fattening ability		
Sexual precocity		
Mothering ability		
Other (specify)		

4.17. Do you select best bulls as parents of the next generation with in your cattle ? ______ *(1=Yes, 2=No)*

4.18. If **Yes**, at what age ? ______ Years

4.19. If **Yes**, what are your selection criteria for bulls ?

Criteria	Tick	Rank

Size / appearance		
Color		
Horns		
Growth		
Character		
Libido		
Pedigree		
Fattening ability		
Sexual precocity		
Adaptability		
Other (specify)		

4.20. Do you allow a bull to mate his :
a. Mother _______ *(1=Yes, 3=No)*, Reason………………………………………………………………………
b. Daughter _______ *(1=Yes, 3=No)*, Reason……………………………………………………………………
b. Sister _______ *(1=Yes, 3=No)*, Reason…………………………………………………………………...

4.21. Do you allow your bull to serve cows other than yours ?

Reason

a.*Yes* _______ ……………………………………………………................................
b. *No* _______ ………………………………………………………………………………

4.22. Do you allow your cows to be served anyone else bull ?

Reason

a.*Yes* _______ ……………………………………………………………………………….
b. *No* _______ ………………………………………………………………………………

4.23. Do you practice castration ? _______ *(1=Yes, 2=No)*

4.24. If **Yes**, what are the reasons ? _______ *(1= Contrôle mating, 2= Fattening, 3= Better temperament, 4= Other (Specify))* ……………………………………………………………………………………………….

4.25. At what age do you castrate your bull ? _______ Years

4.26. Number of castrated animals in your herd________

4.27. Do you use castrated bulls as working animals ? _______ *(1=Yes, 2=No)*
4.28. If No, Why ?..

4.29. Do you fatten castrated bulls ? _______ *(1=Yes, 2=No)*
4.30. If No, Why ?..

4.31. Have you ever heard of Artificial Insemination ? _______ *(1=Yes, 2=No)*
4.32. If **Yes**, from who ? _______ *(1=Other framer, 2=Livestock technician, Other (Specify))*

4.33. Do you practice Artificial Insemination ? _______ *(1=Yes, 2=No)*
4.34. If **Yes**, what trait of your breed do you like to improve ? _______ *(1=Milk production, 2=Template, 3=Resistance to diseases, Other (Specify))* ....

4.35. What breed semen to you use ?..

V. FEEDS AND FEEDING

5.1. What are the major cattle feed resources in your area?

Feed resource	**Wet season**	**Rank**	**Dry and cold season**	**Rank**	**Dry and hot season**	**Rank**
Communal grazing land						
Crop residue						
Cut grasses and browes						
Cultivated forage						
Hay						
Concentrate						
Other (specify)						

5.2. What are the grazing methods in your area in different season?

Grazing methods	**Wet season**	**Dry and cold season**	**Dry and hot season**
Free grazing			
Herded			
Cut and carry			
Tethering			

5.3. Do you provide concentrate to your cattle? ________ *(1=Yes, 2=No)*

5.4. If **Yes**, when do you provide concentrate to your cattle? _______ *(1=Wet season, 2=Dry and cold season, 3= Dry and hot season, 4=Anytime)*

5.5. What type of concentrate and for wich type of cattle?

	Class of cattle					**Rank**
	Calves	**Lactating cows**	**Pregnat cows**	**Sick cattle**	**Bull**	
Home made grain						
Bran						
Oil seed cake						
Brewery products						
Other (Specify)						

5.6. If **No**, what are the reasons? _______ *(1=Expansive, 2=Not available, 3= No need to offer, 4= Other (Specify))* ………………………………………………………………………………………….

5.7. Watering

	Number / day	Sources of *water (1=Natural, 2=Well, 3=Drilling, 4=Other (specify))*	Difficults *(1=Accessibility, 2=Availability, 3=Distance, 4=Other)*
Wet season			
Dry cold season			
Dry hot season			

VI. HERDING

6.1. How are your cattle herded during grazing time? _______ *(1= With other species, 2= Separately, 3= No control)*

6.2. If they are herded separately, in which season and the reason?

Season Reason

a. ________ ………………………………………………………….

b. ________ ………………………………………………………….

6.4. Who do the different tasks and decides on benefits obtained from cattle?

Task	**Involved persons**				
	Husband	**Wife**	**Girls**	**Boys**	**Hired labor**

Herding					
Care of calves					
Animal and product selling					
Watering					
Milking					
Cleaning					
Product processing					
Castration					
Cut and carry grasses					
Other (specify)					

6.5. Do you practice transhumance? _______ *(1=Yes, 2=No)*

	Reasoon *(1=Water, 2=Forage, 3=Conflict, 4=Other (Specify))*	Destination
Wet season		
Dry cold season		
Dry hot season		

VII. HEALTH

7.1. Major cattle disease, season of occurrences and traditional treatement.

Local name	**Seasons**	**Causes**	**Conta gious**	**Animal affected**	**Local treatement**
1					
2					
3					
4					

Season: 1= Wet Season, 2= Dry and cold season, 3= Dry and hot season, 4=Anytime, ; Contagious : 1= Yes, 2= No ; Animal affected : 1= Calves, 2= Heifers, 3= Young bulls, 3= Cows, 4= Bulls, 5=All aniamls; Local treatement 1= yes, 2 = No

7.2. Local treatement of diseases

	Nature of treatement (1=Plants, 2=Fetish, 3=Other	If plant, give the used organ	Methods
1			
2			
3			
4			

Organ: 1=Leaves; 2=Root; 3=Twig; 4=bark; 5=fruit; 6=flowers 7=sap; other (specify)

7.3. Do you get vaccination service for your cattle? _______ *(1= Yes, 2= No)*

7.4. If **Yes**, when? _________ *(1= When disease out brake occur, 2= Anytime in a year, 3= Before disease out brake, 4=Other (specify)……………………………………………………………………………………….*

7.5. Where do you get medecine and vaccination? _______ *(1= Livestock office, 2= NGO, 3= Private veterinary office, 4= Other (Specify)) …………………………………………………………………….*

7.5. How many cattle died last year in your herd?

Category	Number of death	Reason of death *(=Disease, 2= Predator, 3= Mechanical, 4= Other (Specify))*
Cow		
Bull		
Young bull		
Heifer		
Calf		
Castrated		

VIII. PRODUCTS AND UTILIZATION

8.1. What breed do you sell preferentially? _______ *(1=Baoulé, 2=Zebu, 3=Crossbred)*

8.2. Why? ....

8.1. What is the common market age of male cattle? _______ Years

8.2. What is the common market age of female cattle? _______ Years

8.3. Which class of cattle do you sell first in case of cash need?

Class	**Rank**
Male calf	
Female calf	
Young bull	
Heifer	
Breeding bull	
Breeding cow	
Castrated	

8.4. Where do you sell your cattle? _______ *(1=At farm, 2=At market, 3=Other (Specify))*

8.5. If 1, why? ________ *(1=Market is far, 2=Does not know market system, 3=Other (Specify))*

8.6. If 2, who sell? _______ *(1=Himself, 2=Middleman, 3=Other (Specify)*

8.7. If middleman, why? ....

8.8. Do export your animals in other country? ________ (*1=Yes, 2=No*)

8.9. If Yes, what country? __________________

8.10. If Yes, Why…………………………………………………………………………

8.11. Who set the animal price? _______ *(1=Farmer, 2=Middleman, Other (Specify))*

8.12. What are the roles of middleman? _______ *(1=Search buyer, 2=Facilitate the transaction, 3=Certify sales, 4=Other (Specify))*

8.13. Who pay the middleman ? _______ *(1=Seller, 2=Buyer, 3=Other (Specify))*

8.14. How much do you pay the middleman for cattle sold ? _______CFA

8.15. Are you satified by midlleman service ? _______ *(1=Yes, 2=No)*

8.16. Why……………………………………………………………………………………….

8.17. With what type of boyer do you usually sell your cattle ? _______ *(1=Butcher, 2=Farmers, 3=Intermediate trader, 4=Other (Specify))*

8.18. Whith what type of buyer market is most profitable ? _______ *(1=Butcher, 2=Farmers, 3=Intermediate trader, 4=Other (Specify))*

8.19. Are markets accessible for all the farmers ? _______ *(1=Yes, 2=No)*
8.20. If No, why ?...

8.21. When Baoulé cattle is most sold in market ? _______

8.22. Is there a preferential market for Baoulé cattle ? _______ (1=Yes, 2=No)

8.23. If Yes, where and Why ?...

8.24. What kind of purchaser damand most Baoulé cattle ? ________ *(1=Buchers, 2=Farmers, 3=Intermediate traders, 4=Other (Specify))*

8.25. Why ?...

8.26. What are the main constraints of Baoulé cattle marketing ?

Constraints	**Tick**	**Rank**	**Solution proposed**
Unfavorable price			
Lack of market			
Lack of buyer			
Lack of road			
Other (specify)			

8.27. Do you slaughter cattle for household consumption ? _______ *(1=Yes, 2=No)*

8.28. If Yes, how frequent ? _______ *(1= For festival, 2= Whenever slaughter age animals is available, 3= Wedding, 4= Births in family, 5= For guests, 6= Circumcise, 7= At funeral, 8= Other (specify))*……………………………………………………………………………………………….

8.29. Which sex are usually slaughter ? _______ *(1= Intact male, 2=Female, 3=Castrated)*

8.30. What is the average age of slaughter ? Male_______ Years Female_______Years

8.31. What is the milk production per day per cow ?

Breed	Number of Lactating cows	Wet saison	Dry cold season	Dry hot season	Lactation lenght
Baoule cattle					
Crossbreed					
Zebu cattle					

8.32. Frequency of milking ? ________ *(1= Once, 2= Twice a day, 3= Three times a day)*

8.33. Milk consumption and sale.

	Home cosumption (L)	Sale (L)	Average price of liter
Wet season			
Dry cold season			
Dry hot season			

8.33. Do you process milk into other product ? ________ *(1= Yes, 2= No)*

8.34. If yes, what are the products ? ________ *(1= Yogurt, 3= Buter, 4= Other (Specify))*
…………………………………………………………………………………………………….

8.35. Do you practice weaning ? ________ *(1=Yes, 2= No)*

8.36. If **Yes**, average weaning age of calf ? ________Mounths

8.37. Milk feeding up to weaning ________ *(1= Unrestricted suckling, Restricted suckling, 3= Bucket feeding, 4= Other (Specify))* …………………………………………………………………………….

IX. HOUSING

9.2. What type of barn do you use for your cattle ? ________ *(1= No barn 2= Temporary barn, 3= Permanent barn)*

9.3. Are calves housed together with adult cattle ? ________ *(1=Yes, 2= No)*

9.4. Are cattle housed together with other animals ? ________ *(1= Yes, 2= No)*

9.5. If Yes, which animals housed together with cattle ? ________ *(1= Sheep, 2= Goats, 3= All species)*

X. MANAGEMENT OF MANURE

10.1. Do you collect dung from your barn ? _____ *(1=Yes, 2=No)*

10.2. If Yes, what is the rythm of collection ? _____ Per *day*

10.3. After collection where and how do you stock your manure? _____ *(1=In pile and covered, 2=In pile and no covered, 3=Compost tank, 5=Ohter (Specify))* ……………………………………………………......

10.4.What do you use dung for? ______*1=Sale; 2=Use for crops production; 3=Gift, 4=Other (Specify)*

XI. ORGANIZATIONAL AFFILIATION AND TRAINING

11.1. Are there any farmers'orgnaisation in your area ? ______ *(1=Yes ; 2=No)*

11.2. Are you affiliated to farmers' organisation ? ________ *(1=Yes ; 2=No)*

11.2. Had you got a training about your activity before ? ______ *(1=Yes ; 2=No)*

11.3. If **Yes :**

1) Year : ______
2) Type of training : ………………………………………………………………………….
3) Who have organised? _____ *(1=Govenment office, 2=NGO, 3= Private veterinary office, 4= Other (Specify))* ……………………………………………………………...
4) Do you think the training was useful for? ______ *(1=Yes ; 2=No)*
5) If Yes, in what way? ....
6) If No, what are the reasons? ....

XII. CROP PRODUCTION

12.1. Do you practice crop production? _____ *(1=Yes; 2=No)*

12.2. Total land exploited _____*ha*

Type of crops	Land exploited (ha)	Production (kg)	Used as animal feed Yes/No	Products used (1=Residus, 2=Seed, 3=Other)	Animals fed

Animal fed : 1=Lactating cows, 2=Pregnant cows, 3=Breeding bulls, 3=Illness animals, 4=Young animals, 5=Other

XIII. MAIN CONTRAINTS OF LIVESTOCK

13.1. What are the major problems of cattle production in your area? (Rank according to their severity)

Constraint	**Tick**	**Rank**	**Solution proposed**
Disease			
Feed shortage			
Water shortage			
Labour shortage			
Predator			
Genotype			
Lack of finance			
Lack of extensive service			
Lack of market			
Drought			
Other (Specify)			

THANK YOU VERY MUCH !

Appendix 2: Format for baseline and routine recording

ANIMALS PERFORMANCES RECORDING

Date: ______________________ Name of farmer: ____ Phone: ____________________________

Commune: __________________ Village: _________________________ Geographical location: ___________________________________

Tag	Sex (M, F)	Age	Genotype (B, C, Z)	Statute (Cw, H, M, C)	Height at Withers (HAW)	Body Length (BL)	Chest girth (CG)	Weight (Kg)	ID_Dam	ID_Sire	Color	ID_Blood Sample

Sex: M= male, F= female; **Genotype**: B= Baoulé, C= Crossbreed, Z= Zebu, **Statute**: Cw= cow, H= heifer, M= male; C= castrated / oxen

Appendix 3: Form for own herd ranking

1. **Morphological measurment**

Date :	**Commune :** **Name of farmer :**			
Traits	**1st best Animal**	**2nd best Animal**	**3rd best Animal**	**Worse Animal**
ID				
Age				
Color				
Head length (HL)				
Cranial length (CL)				
Facial lenght (FL)				
Head width (Hw)				
Facial width (Fw)				
Ear legth (EL)				
Horn length (HL)				
Circomference of Muzzle (CM)				
Body length (BL)				
Scapulo-ischial length (SCIL)				
Hip width (Hw)				
Tail length (TL)				
Teat length (TL)				
Chest girth (CG)				
Body Weight (Kg)				
Height at withers (HAW)				
Chest depth (CD)				
Height at sacrum (HAS)				
Chest width (Cw)				
Body condition score (BCS)				
Reason of ranking				
Origine of animal				
ID_Dam if born in herd				
Place if bought				

Reason of ranking : 1=Size, 2=Milk yield, 3=Fertility, 4=Docility ; 5=Other
Origine : 1=Born in the herd, 2=Bought, 3=Rent, 4=Other
Achat ou emprunt : 1=Chez un voisin, 2=Un autre éleveur du village, 3=Dans un autre village

2. **Phenotypic characterization**

Traits	**1st best Animal**	**2nd best Animal**	**3rd best Animal**	**Worse Animal**
Head profil				
Ears shape				
Horns shape				
Horns color				
Hair type				
Coat pattern				
Coat color				
Back profil				

Head profil (1=Straight, 2=Concave, 3=Convex) ; Ears shape (1=Horizontal, 2=Drooping, 3=Erected) ; Horn shape (1=Wheel, 2=Cressent, 3=Cup, 4=Lyre) ; Horns color (1=Black, 2=Gray, 3=Bicolor) ; Type of hair (1=Short, 2=Long) ; Coat pattern (1=Simple, 2=Pie, 3=Spotted) ; Coat color (1=Black, 2=Gray, 3=Red ; 4=White, 5=Other) ; Back profil (1=Straight, 2=Concave, 3=Convex)

Curriculum Vitae

Name: Dominique Ouédraogo

Date & Birth Place: 31/12/1983

Nationality: Burkinabè

Email: ouedom@gmail.com

Skype: ouedom

ORCID: https://orcid.org/0000-0001-5752-1534

EDUCATION

Since October, 2017: PhD student in Animal Breeding and Genetics, University of Natural Resources and Life Sciences (BOKU), Vienna, Austria.

2009 – 2011: Msc in Livestock Production Systems, University Nazi Boni, Bobo-Dioulasso, Burkina Faso.

2005 – 2008: Engineer degree in rural development / Animal sciences, University Nazi Boni, Bobo-Dioulasso, Burkina Faso.

2003 – 2005: Degree of general university studies / Biology and Chemistry, University of Ougadaougou.

WORK EXPERIENCE

Since 2016: PhD Student, APPEAR funded project 120: LocaBreed "Local Cattle Breed of Burkina Faso: Characterization and Sustainable Use".

Since 2013: Part time lecturer in Animal Sciences, University of Dédougou, Burkina Faso.

2014 – 2015: Collaboration as Research Assistant in Volkswagen funded project "Resources, Livelihoods, Management, Reforms and Process of Structural Change", Environmental and Agricultural Researches Institute (INERA), Burkina Faso.

2012 – 2013: Collaboration as Research Assistant in Volkswagen funded project "Cross-location modeling of Resources Use Efficiency in West African Urban Livestock Production", International Center of Research on Livestock in Subhumide Areas (CIRDES), Burkina Faso.

List of publications

Peer-reviewed journal articles

Ouédraogo, D., Ouédraogo-Koné, S., Yougbaré, B., Soudré, A., Zoma-Traoré, B., Khayatzadeh, N., Mézáros, G., Traoré, A., Sanou M., Mwai, A.O., Wurzinger, M., Burger, P.A., and Sölkner, J., 2020. Population structure, admixture and inbreeding of three local cattle populations managed by community-based breeding programs in Burkina Faso**.** Accepted in Journal of Animal Breeding and Genetics

Ouédraogo, D., Soudré, A., Ouédraogo-Koné, S., Yougbaré, B., Zoma, B.L., Arnaud Stéphane R. Tapsoba, A.S.R., Mézáros, G., Burger, P., Khayatzadeh, N., Wurzinger, M., Traoré, A., Okeyo, A.M., and Sölkner, J., 2020. Selection of breeding bulls in community-based cattle breeding programs in Burkina Faso. Bull. Anim. Prod. Afr. 68, 103-111

Ouédraogo, D., Soudré, A., Ouédraogo-Koné, S., Zoma, B.L., Yougbaré, B., Khayatzadeh, N., Burger, P.A., Mézaros, G., Traoré, A., Okeyo, A.M., Wurzinger M., and Sölkner J., 2020. Breeding objectives and practices in three local cattle breed production systems in Burkina Faso with implication of the design of breeding programs**.** Livest. Sci. 232, https://doi.org/10.1016/j.livsci.2019.103910

Yougbaré, B., Soudré, A., **Ouédraogo, D.,** Zoma, B.L., Arnaud S. R. Tapsoba, A.S.R., Sanou, M., Ouédraogo-Koné, S., Burger, P., Wurzinger, M., Khayatzadeh, N., Tamboura, H.H., Taroré, A., Sölkner J., and Mézáros, G., 2020. Morphometric characterization of purebred and crossbred Baoulé cattle in Burkina Faso. Acta Agri. Scandi., Section - A Animal Science, https://doi.org/10.1080/09064702.2020.1825785

Conference papers

Ouédraogo, D., Soudré, A., Ouédraogo-Koné, S., Yougbaré, B., Zoma, B.L., Arnaud Stéphane R. Tapsoba, A.S.R., Mézáros, G., Burger, P., Khayatzadeh, N., Wurzinger, M., Traoré, A., Okeyo, A.M., and Sölkner, J., 2019. Implementation of community-based cattle breeding programs in Burkina Faso. 7th All African Conference of Animal in Agriculture (AACAA), July 29 – August 2, 2019, Accra, Ghana.

Ouédraogo, D., Soudré, A., Ouédraogo-Koné, S., Zoma, B.L., Yougbaré, B., Khayatzadeh, N., Burger, P.A., Mézaros, G., Traoré, A., Okeyo, A.M., Wurzinger M., and Sölkner J., 2019. Breeding objectives and traits preference in three local cattle breed production systems in Burkina Faso. Tropentag 2019, September 18 – September 20, 2019, Kassel, Germany.

Yougbaré, B., Soudré, A., **Ouédraogo, D.,** Zoma, B.L., Arnaud S. R. Tapsoba, A.S.R., Sanou, M., Ouédraogo-Koné, S., Burger, P., Wurzinger, M., Khayatzadeh, N., Tamboura, H.H., Taroré, A., Sölkner J., and Mézáros, G., 2019. Morphometric characterization of purebred Baoulé and their crosses with local Zebu cattle in Burkina Faso. Tropentag 2019, September 18 – September 20, 2019, Kassel, Germany.