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Review

Sustainable Management of Animal Genetic Resources to Improve Low-Input Livestock Production: Insights into Local Beninese Cattle Populations

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Abstract: Persistent food insecurity, along with climate change pressures, urges on the definition of suitable strategies to support the transformation of low-input livestock farming in developing countries. Advances in genomics and information technologies are valuable opportunities for achieving the required improvement, but their implementation implies access to technical and financial resources with appropriate adjustment in the local context. Addressing extensive cattle production in Benin, we focus on animal genetic resources (AnGR) and corresponding approaches aiming for a durable breeding improvement based on sustainable management strategies. Specifically, smallholder breeding goals are revised, and novel strategies for proper organization, sound data collection, and scientific investigations are explored. Further emphasis addresses the enhancement of farmer management practices, including valuable traditional knowledge; and breeding strategies to improve animal performances considering robustness and further traits favored by the farmers. Against such a background, it is imperative that political, institutional, and scientific collaborations reinforce research capacities and technical and financial resources. In the given context, the current review article provides policymakers and national and international researchers with practical guidance based on scientific criteria for a smallholder livestock amelioration in Benin, scalable to other countries in sub-Saharan Africa.

Keywords: smallholder cattle farming; genetic improvement; indigenous breeds; breeding goals; community-based breeding program; climate change

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1. Introduction

Agricultural production, especially livestock, in developing regions is characterized by a high vulnerability, which is intensified by diverse challenges, including climate change [1]. Increasing temperatures and humidity stimulate further environmental stressors, such as the occurrence of infectious and non-infectious cattle diseases or seasonal fluctuations in feed resources. Hence, climate change poses serious risks to the sustainability of livestock systems and threatens the livelihoods of hundreds of millions of poor livestock farmers [2–5]. Simultaneously, people in sub-Saharan Africa are highly affected by a deficit in food supply, implying continuously increasing demand for livestock products due to rapid urbanization and population growth [6,7]. The increasing challenge to ensure food security combined with the uncertain future in developing countries suggest strengthening animal genetic resources (AnGR) that are able to survive, grow, and reproduce in harsh environments. Researchers attributed the current resilience of the African pastoralism to the outstanding experiences of the herders in maintaining and managing

local breeds [8–10]. African indigenous breeds have adapted to diverse, stressful tropical environments by undergoing, over centuries, natural and artificial selection. They have acquired a range of unique adaptive traits, such as resistance to disease and heat, tolerance to water scarcity, and ability to cope with poor-quality feed [11,12]. However, such a unique pool of AnGR is threatened with extinction while the development of breeding strategies considering smallholder management practices is neglected [4,7,13,14].

The need to conserve biodiversity for food production is acknowledged worldwide nowadays, but strategies to use African AnGR for improving livestock productivity and sustaining smallholder livelihoods are not thoroughly elaborated [8,15–17]. Consequently, several livestock development programs on the African continent have failed [18–20]. In addition, efforts to exploit up-to-date technologies for improving low-input livestock farming are unevenly observed across the continent. There are only a few reports from the eastern and southern African regions or Sahelian countries where the livestock production sector is more dynamic and represents a national priority [19,21,22]. The existing proposals and recommendations in this regard are not directly applicable or transferrable to various areas due to the complexity and diversity characterizing African farming systems [7]. The current situation indicates the necessity to contextualize livestock development schemes within the framework of livestock keepers' smallholder preferences and practices, as well as local economic and ecological environments [23].

In Benin, strategies for improving smallholder cattle production are very limited, whereas cattle production is vital for reducing poverty and the deficit in animal protein for the growing population in the country. In comparison with other animal species (poultry, sheep, goat, pigs, etc.), smallholder cattle herds are the main source of meat in the country, contributing to more than 50% of the national meat production [24,25]. They provide not only food but also regular revenue and social security assets for poor farmers as well as for numerous people involved in the meat, cheese, and animal trades [26–28]. Cattle farming represents a main rural activity in several Beninese agro-ecological regions and is increasingly integrated into crop farming for draught or to improve soil fertility [14,29]. The importance of cattle production in Benin is continuously growing due to the increasing movements and settlements of several pastoralists from neighboring countries [30]. In parallel, the intranational and cross-border mobility of pastoral herds is significantly affecting local animal genetic and pastoral resources [31]. These trends are expected to increase in the coming years, considering the advancement of the Sahelian desert towards the northern regions of Benin, as an evident effect of climate change [13,29]. Therefore, it is urgent to develop resilient breeding systems to increase cattle productivity and to mitigate the impacts of ecological pressures on smallholder livelihoods [7,32].

Capitalizing on the existing knowledge of Beninese cattle production systems along with the prevailing challenges [14,33,34], we review current literature and recommendations on livestock development, management of AnGR, and breeding programs to propose a framework for improving smallholder livestock keepers' livelihoods in Benin through sustainable management of their cattle genetic resources and improvement of livestock production.

2. Genetic Resources in the Context of Cattle Production in Benin

2.1. Diversity of Cattle Breeds in Benin

2.1.1. The Indigenous Cattle Breeds of Benin

Cattle production in Benin is based on two indigenous shorthorn taurines (Somba and Lagune) and a large diversity of indigenous hybrids, including the Borgou and Pabli (Table 1) [35].

The unicity and indigenous status of the shorthorn taurine are supported by their exclusive presence in West Africa since 2500 BC [36,37]. These breeds acquired their current trypanotolerance through genetic adaptation to trypanosomiasis pressures in the

rainforest regions of central and western Africa [36]. The savannah shorthorn taurine cattle in Sudano-Guinean savannahs regions diverge from the dwarf (forest) shorthorn populating the coastal regions of West Africa with noticeable phenotypic and genetic differences [31,36].

In Benin, savannah shorthorns are represented by the Somba cattle (Figure 1a) distributed in the hilly region of Atacora in Benin and Togo [38]. It is reported that the Somba cattle originated from north-central Nigeria and constitute the founder of Baoule or Lobi in Ghana, Burkina Faso, and the Ivory Coast, where they migrated later [36]. The Lagune breed (Figure 1b), the Beninese dwarf shorthorn taurine, is described as the shortest cattle breed in the world [36]. Its small body size is attributed to adaptations to subsistence farming systems in the region [36,39]. Lagune cattle from Benin, known as Dahomey cattle, are reported in diverse countries in Africa (Congo, Zambia, and Gabon) and Europe (Germany, Austria, Czech Republic, and Switzerland) [36,40]. The production environment, phenotypic characteristics, and reproductive performances of Somba and Lagune cattle under extensive management systems are extensively described in recent studies [33,41–44]. Both Somba and Lagune breeds are well appreciated by farmers for their ease of management, resistance to diseases, tolerance to feed and water shortages, and good milk and meat qualities [33,44]. The breeds are also well valued for their sociocultural functions and their contribution to farmers' livelihoods, including integration to crop productions and means of saving or insurance [38]. They are also preferred in markets and fetch higher prices (per kilogram of live weight) compared with other breeds, such as the Zebu [26]. Nevertheless, their small size and low productivity limit their continuous management, as they are continuously replaced by crossbreeds with Zebu cattle [31].

According to genetic analyses (formal tests of admixture and estimation of ancestry proportion), the Borgou breed (Figure 1c) is originally a product of crossbreeding between the shorthorn Somba cattle and the Zebu White Fulani [45]. The Borgou are characterized by higher meat and dairy performances than those of the taurine cattle, and they have adaptive abilities, including tolerance to trypanosomes. In the past, the Borgou was a favorite smallholders' breed given its meat and milk (organoleptic and technological) qualities (over Zebu or other exotic breeds) [46]. No national breed census exists to date, but the breed was reported as the largest cattle population in Benin according to different studies [14,47]. However, the Borgou are stepwisely crossed with Zebus, aiming for higher productivity [31]. Similarly, the Pabli (Figure 1d), a crossbreed between the Borgou and Somba, were described in northwest Benin [48,49]. The status of this breed is uncertain, while diverse products of crossbreeding are increasingly reported in Benin cattle herds. The expanding admixture in the national cattle herds due to both intended and unintended crossbreeding with less adapted Zebu and crossbreeds questions the sustainability of cattle production in the country and requires urgent actions.

(**a**)

(**b**)

(**c**) (**d**)

Figure 1. Photos of Beninese indigenous cattle breeds: (**a**) Somba, (**b**) Lagune, (**c**) Borgou (crossbreed Somba × Zebu White Fulani), and (**d**) Pabli (crossbreed Borgou × Somba).

2.1.2. Other Cattle Breeds Reared in Benin

Several west and central African Zebu cattle breeds supplement the diversity of cattle breeds in Benin (Table 1) [35]. The Zebu breeds, essentially present in Sahelian and other West African countries, have been introduced in Benin through transhumance movements and pastoralist settlements [30,35]. Generally, Zebu cattle are less adapted to the Beninese humid climate than the taurine cattle are, but some Zebu breeds, including the White Fulani cattle, have appreciable adaptive features. Historians and geneticists explain the relative adaptability of Bororo cattle (White Fulani and Red Fulani) by their crossbreeding origins from *Bos primigenius* and *B. indicus* [10,50]. White Fulani cattle are predominant in Benin and are widely used in crossbreeding, as they are simultaneously suitable for draught and milk and meat productions [51]. In addition to Bororo cattle (lyre-horned), shorthorn Zebus are also described in Benin and are represented by the Goudali and Azawak breeds [35,52,53]. The latter Zebu group is originally described as "pure Zebu", with large size and high productive performances [10,54–56]. A major limitation of these breeds addresses their demanding feed requirements [10]. Nevertheless, the crossbreeding of the Azawak with indigenous breeds is currently promoted in extensive, as well as state-owned, farms [53,57]. To date, there is a lack of scientific evaluation addressing the characterization of these crossbreeds and their adaptation to Beninese local conditions. Further Zebu breeds in Benin include the Djeli or Nigerian Fulani, which is mainly reported in Niger [35,58]. However, the low resistance or tolerance of this breed to trypanosomiasis limits its expansion in Beninese pastoral regions [14,52]. The presence of Zebu cattle in several West African countries and the involvement of some breeds in ongoing breeding programs offer possibilities and perspectives for regional collaborative programs [19].

In addition to the Zebu, the N'Dama and Girolando are also reported in Benin [59,60]. The Longhorn Taurine N'Dama cattle were introduced on the Okpara state-owned farm in north Benin in 1952 and 1993 in order to improve Beninese indigenous cattle breeds [61]. The N'Dama presented lower productivity than that of the Borgou in Benin and has not been successfully promoted into extensive farms [62]. Consequently, the current N'Dama population exhibited inbreeding depression on the Okpara state-owned farm [63]. The Girolando, a crossbreed from the Asian Zebu Gyr and the Holstein, was first introduced in 2004 for the increase of national cattle milk productivity in Benin [59,60]. The breed is known for high milk performance and adaptation to tropical conditions, including tolerance to heat stress [64]. However, the Girolando cattle are less adopted by smallholders in Benin. They are less productive than expected due to their low adaptation to local productive conditions, including high disease pressures and limited availability

of feed resources [65]. In addition, the Girolando are suspected as a source for the spread of new invasive tick species (e.g., *Rhipicephalus microplus*) in Benin, as in other West African countries where the breed has been introduced [66–68].

Table 1. Characteristics of the cattle breeds in Benin.

Category	Breed Name *	Presence in Benin #	Geographical Distribution in Africa	Frequently Desired Attributes by Farmers	Weakness	Observations	References
Savannah shorthorn	Somba	Northwest Benin (Boukombe)	Northeast Togo	Tolerance to diseases and feed and water shortages; good milk and meat qualities; good temperament and draught ability; ease of management; high sociocultural value	Small size, low milk and meat productivity	Reduction of population size due to diseases and lower effect of admixture	[31,33]
Dwarf shorthorn	Lagune	Southern and central Benin	Congo, Zambia and Gabon (known as Dahomey cattle)			Moderately affected by admixture with Zebu	[31,43]
Indigenous cross-breeds	Borgou	Across the country	Known as Ketekou or Keteka in West Africa	Tolerance to trypanosomiasis and feed and water shortages; endurance and draught ability	Lower milk and meat productivity than the Zebu	Highly affected by admixture with Zebu	[14,31,35,52]
	Pabli	Northwest Benin (Kerou)	-	Share similar characteristics with the Borgou	-	Less investigated and reported as extinct	[31,69]
Lyre-horned Zebu	White Fulani or White Bororo [1]	First most reported Zebu cattle in Benin	Central and western Africa	More resistant to diseases and tolerant to heat than other Zebu are; good performances in milk, meat and draught	Exigent in feed and water resources: practice integral and low grazing.	Large diversity and admixture within the population Its adaptive features are barely investigated	[10,36,51,70–72].
	M'Bororo or Red Fulani [2]	Third most reported Zebu cattle in Benin	Central and western Africa	Ability to walk long distances; intelligent animal, docile and attached to its owner (less susceptible to theft)	Less trypanotolerant, very exigent in feeding: practice selective grazing	Poorly investigated for population genetic characterization	[10,72–74]
Shorthorn Zebu	Gudali [3]	Second most reported Zebu cattle in Benin	Nigeria, Ghana, Cameroon, Central African Republic, and Mali	Large size, growth, and milk performance; exploits large variety of feed resources in the dry season	Poor carcass yield: less than that of White Fulani Limited in walking	Large genetic diversity: many subpopulations; current distribution unknown in Benin	[52,54–56,72,75,76]

	Azawak [4]	Very rare in extensive herds and crossbreed in state-owned farms	Mali, Niger, and Nigeria	Best milk performance within indigenous WA cattle, good meat performance, and excellent adaptation to drought	Requires high-quantity and qualified feed; slow in walking long distances	Currently promoted for crossbreeding with the indigenous breeds in extensive and state-owned farms The breed and resulting crossbreeds remain largely undescribed	[53,56–58,77]
Undescribed (crossbreed) Zebu	Djeli or Nigerian Fulani [5]	More rare than other Zebu	Niger	Good reproductive and milk performance, weight gain, and docility	Less trypanotolerant, with medium size and body weight	Remains largely undescribed No study on genetic diversity and relationship with other breeds	[52,58,77]
Longhorn African taurine	N'Dama	Mainly kept on state-owned farms	Western and central Africa	Trypanotolerance and resistance to diseases	Less productive than the Borgou and Zebu are	High inbreeding in the current population on state-owned farms	[61–63,72,78]
Tropical crossbreed	Girolando	Kept on Kpinnou and Okpara state-owned farms	Ivory Coast, Burkina Faso, and Senegal	High milk performance	Very susceptible to disease pressures and exigent in feed and water resources	Low productivity in Benin due to inadequate environmental conditions and source of tick invasion in West Africa	[60,66,67,79,80]

***** Others breed names: [1] Yakanaji, Daneeji, Akuji, or Bunaji [51,81]. [2] M'Bororo, Bororo, Mbororooji, Bodeeji, or WoDaaBe [35]. [3] Goudali, Sokoto Gudali Bokoloji, Rahaji, or Zomanta [35,81]. [4] Azaouak, Azawa, Azawaje, Tuareg, Adar, Darmeghou, or Tagama [56,82] [5] Djelli, Djelliji, Diali, Djalli, Jaliji, or Peuhl Nigérien [35,56]. [#] There is to date no official statistics on the population size of cattle breeds in Benin. The information presented here is based on systematic surveys from previous publications.

2.2. Management of Cattle Genetic Resources in Benin

2.2.1. Cattle Production Systems and Major Constraints

In Benin, cattle are mainly kept in low-input extensive farming systems, as intensive or commercial herds are uncommon. The major production systems comprise sedentary and mobile herds. Sedentary herds are of small size, dominated by indigenous taurine cattle, and principally rely on village pastures the whole year for feeding [14,83–85]. Mobile herds are larger and mainly owned by traditional pastoralists (Peulh, Fulani, Fulbe, MbororooBe). They seek feed and water resources within and beyond their principal encampments or regions through low- or high-amplitude transhumance or migration [14,83,86].

The shortage of feed and water resources represents a major limitation for cattle farming [87–89]. The distribution and availability of feed and water resources are driven by a high variability of climatic conditions across the country [47,90,91]. Simultaneously, the majority of pastoral rangelands and transhumance corridors have faced intensive degradations due to overgrazing and bush fires. Rangelands and transhumance corridors are frequently replaced by crop farms (especially cash crops, such as cotton), which have been increasingly expanded in pastoral regions. The competition in land use resulting in reduction of pastoral rangelands is enhanced by demographic explosion, social considerations, and land property rights [92,93]. Simultaneously, the delimitation and management of

pastoral resources by local or national authorities, as well as their scientific characterization, are barely observed [94,95].

High rates of mortality and disease occurrence constitute the second main constraints in the Beninese cattle herds [14,33]. Major diseases (several are neglected zoonoses) reported in Benin include viral (foot-and-mouth disease and lumpy skin disease), bacterial (anthrax, contagious bovine pleuropneumonia, and *Mycobacterium tuberculosis*) and parasitic (trypanosomiasis and *Fasciola gigantica*) infections [33,65,96–102]. The extensive systems, grazing on communal pastures, and national and cross-border herd mobility and trade favor the spread of diseases in the agro-pastoral areas [27,101,103–105]. The diagnosis and monitoring of livestock diseases are limited, and prevalence data are scarce. The treatment and prevention of disease through vaccination are also deficient, being based mainly on self-medication with medicinal plants or on important quantities of antibiotics and trypanocides [106,107]. According to Dognon et al. [106], animals are generally over- or underdosed because animal body weights are not correctly estimated and farmers have no expertise in drug usage. The scarcity of professional assistance in the treatment of the disease increases drug resistance, increases mortality in cattle herds, and impairs the quality of cattle products [108,109]. For instance, researchers reported more than 68% of resistance to the *Diminazene aceturate* trypanocide in West African cattle herds [109].

2.2.2. Institutional Management of AnGR in Benin

In recent years, noticeable efforts have been made regarding the characterization of production systems and phenotypic characterization of Beninese cattle breeds [14,33]. Nevertheless, there is a lack of knowledge addressing cattle production and the description of AnGR in Benin. The genetic characterization of AnGR is quite unexplored in Benin. Only a few studies have revealed a high level of diversity and quite large genetic distances between the different populations [31,45,53,110,111]. Considering the existing genomic studies [31,45,53,110,111], we assume only a thousand local animals were genotyped (with microsatellites and 50 K Illumina SNP), which is a very small fraction in relation to the whole national cattle population [24]. Research activities on AnGR are limited by logistic constraints in data collection related to the extensive production system (including herd mobility), challenging conditions in pastoral areas (farms are hardly accessible and no electrical energy sources on field), absence of national data collection systems, and the lack of qualified technicians, adequate equipment, and infrastructures to collect valid data in the field [41,112,113]. In addition, the involvement of the herders in the development and implementation of research activities is insufficient.

The last national assessment for the "second report on the state of the world's animal genetic resources for food and agriculture" undertaken by the Food and Agriculture Organization (FAO) [16] described a poor institutional context for the management of AnGR in Benin. This is characterized by the absence of national legislation, suboptimal breeding programs or strategies (including artificial insemination breeding), a deficit of relevant infrastructure, poor education, training, and collaboration between the stakeholders (farmers, authorities, traders, and consumers), and a lack of public knowledge and awareness regarding the management of AnGR [114]. This diagnosis contrasts with the reports of the numerous and diverse livestock development projects (PDE I, II, III and PAFILAV) implemented in the country since the 1980s [59,115]. These projects aimed at "modernizing" livestock production in Benin (by addressing livestock feeding, health improvement, genetic improvement, and animal product processing and marketing) have generated very few impacts [60,115]. A typical example is the Milk and Meat Support Project (PAFILAV) targeting the enhancement of the national productivity in cattle milk and meat through crossbreeding with Girolando cattle from Brazil [60]. The generated crossbreed animals barely survive disease pressures, resulting in low productivity despite their controlled management systems [60,79]. The Girolando crossbreeds, like other publicly imported breeds (e.g., N'Dama), are generally kept on state-owned farms and are hardly adopted by smallholders for reasons including fitness and product quality [46,78]. These

examples indicate the critical necessity for a paradigm shift and the conception of relevant strategies adapted to local environmental conditions and the needs of smallholders.

3. Pathways for the Management and Improvement of Cattle Genetic Resources in Benin

3.1. Livestock Development Objectives and Strategies

3.1.1. Breeding Goals of Smallholders

The demand for milk and large-sized cattle in Benin is growing continuously and is secured by the importation of meat and dairy products [44,60]. However, targeting for breeding objectives and breeding goals that only include meat and milk productivity, is usually ineffective, as observed in diverse African countries [18]. Indeed, smallholders perceive the improvement of their herds' overall productivity in a more complex system than that only focusing on increasing growth and milk performances. Previous studies indicated that smallholders are mainly concerned with the maintenance of their herds as insurance or productive assets for primary household consumption and a source of regular or diversified familial income [116,117]. Therefore, the definition of specific and non-classical breeding goals, including farmer objectives and their desires of ideal animals, is fundamental for any promising livestock improvement strategy (Figure 2) [118,119].

Smallholder perceptions of a breed and their decision to keep or "create" a breed are driven by personal interests, sociological and historical backgrounds, production objectives, production system, and environmental constraints. Although high diversity in herder interests and breeding objectives is observed in Benin and other African countries, major distinctions between the agro-pastoralists and mobile pastoralists address sociocultural characteristics and management systems (Table 2). In Benin, smallholder agro-pastoralists (practicing cattle farming as second activities) mainly value the sociocultural functions of their animals and their utility in cropping activities [38]. These farmers principally focus on draught ability, manure, morphological appearance (such as specific coat color for cultural purposes), and animal docility. They prefer animals that are robust and easy to keep, which may be defined by adaptive traits such as resistance to disease, tolerance to feed, and water shortages or animal longevity [33]. In contrast, mobile pastoralists favor animal fertility, as the breeding of large cattle herds and milk production are essential components of their culture and the basis of their social and wealth status [120]. The mobile pastoralists are more oriented toward milk yield and quality, as well as growth performance. However, adaptive traits are also important, especially with the worsening agro-ecological conditions. Boutrais [76] reported that mobile pastoralists first created a new "crossbreed" in order to adapt to new environmental conditions, but they upgraded this new crossbreed to consider the characteristics of their ideal cattle (large conformation and high milk productivity). The later observation indicates that interests of farmers are not static and may be influenced by sociological, economic, and ecological constraints. Therefore, an exhaustive and regular assessment of farmers breeding goals would be required.

Table 2. Major farmer preferences and breeding objectives generally observed in African low-input cattle production systems.

	Agro-Pastoralists	**Mobile Pastoralists**
Production	Meat quality Draught ability	Live weight Milk yield Milking easiness Milk quality (cheese making)
Reproduction	Calving ease Calf survival	Fertility (short calving interval) First calving at young age

Robustness	Ability to produce with limited feed and water (quantity and quality) Resistance to diseases (Trypanosomiasis) Longevity	Moderate exigence in feed and water Ability to walk long distances Tolerant to heat stress
Temperament	Docility Ease of keeping	Aggressiveness (against theft)
External appearance	Coat color	Large conformation
References	[14,33,34,38,42,44]	[14,34,35,44,52,76,117]

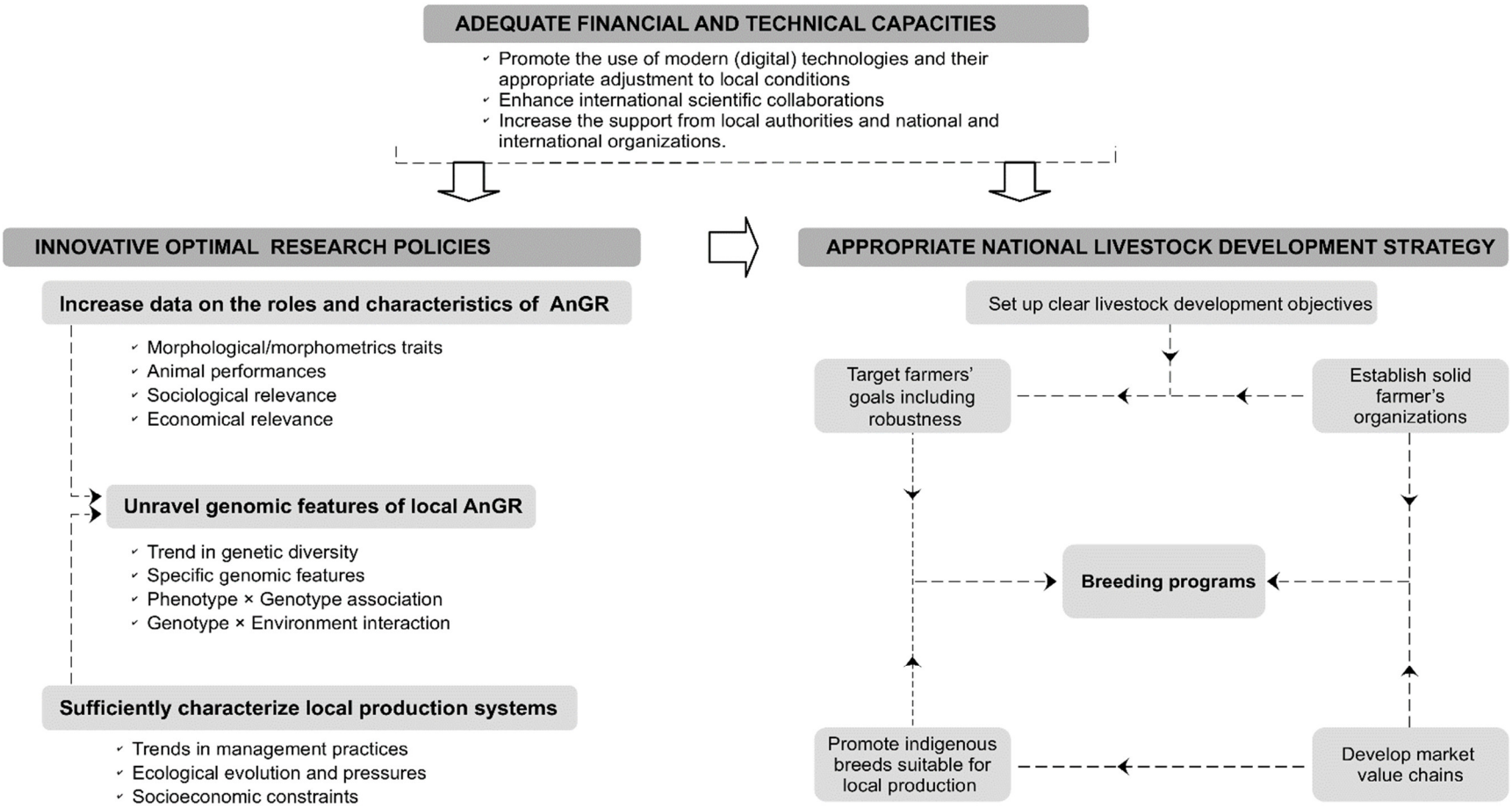

Figure 2. A holistic scheme to address the management and improvement of animal genetic resources (AnGR) in Benin.

3.1.2. Optimization of Phenotyping and Genotyping Strategies

Identifying the breeding goals of farmers and determining suitable breeds for local conditions require the collection and analysis of large-scale and accurate animal phenotype and genotype data in the context of extensive descriptors for environmental and management systems. The current scarcity in data and lack of initiatives in Benin contrast with the diversity of emerging tools and guidelines to support data collection and analysis in low-input livestock production systems [121,122]. This suggests the enhancement of local capacities and the adjustment of up-to-date technologies to provide local, convenient, and cost-effective but powerful strategies for optimal scientific investigations toward the improvement of livestock breeding in Benin [123].

Morphometric traits represent valuable measurements for the phenotypic characterization of AnGR, performance evaluation, and animal selection in both developing and developed countries. Recent studies in Benin reveal that they could be accurately exploited for performance recording (estimation of live body weight) and genetic evaluations [34,113]. Beside morphometric measurements, innovative phenotypes, such as worm fecal egg counts, antibody levels in response to pathogen infections, rectal temperature, respiration rate, and milk content, are valuable indicators to evaluate adaptive features, including heat tolerance, disease resistance, or tolerance [118,124].

Emerging information technology (IT) offers new prospects for systematic collection and analysis of diverse agricultural data [125]. Geographic information systems (GISs) assist in assessing environmental descriptors for genomics and breeding purposes, and experiments have been performed in North Africa [126]. In addition, ecological and epidemiological data from satellite information are freely accessible on various open-source platforms [127]. Zannou et al. [101] exploited satellite images to characterize transhumance corridors, vegetation, and risk of diseases in transhumant herds from Benin and neighboring countries. Similarly, drone technology may help to investigate livestock populations or to support the monitoring and management of pastoral rangelands [128]. In eastern and southern African countries, mobile phone and data loggers are now used to collect large-scale management, health, and performance (milk performance, morphometric traits, or body condition score) data in smallholder households and livestock herds [123,129]. The utilization of mobile phones by increasing numbers of Beninese pastoralists, as observed by Djohy et al. [129], is an attractive opportunity. In addition, the ongoing extension of mobile internet connections and emerging IT competencies in the country are the basis for the development of similar digital applications. Good collaboration between scientists and local IT experts is therefore expected to explore and define innovative phenomics and environomics (large-scale phenotypic and environmental data capturing) systems for livestock research in Benin [130,131].

Regarding genotypic data, the availability of kits and protocols to easily and accurately extract DNA from animal tissues, such as hair samples (conveniently collectable and conservable), enabled animal genotyping in challenging breeding conditions [132]. This revolution has been supported by the development of affordable low- or medium-density single-nucleotide polymorphism (SNP) panels. The majority of commercial SNP chips are sufficient to assess the genome of indigenous breeds in Benin, but these chips are developed for commercial large-scale populations and may be less informative to establish effective genomic selection of African taurine, Zebu, or crossbreeds [133]. Hence, the development of specific medium-density chips suitable for Beninese or West African cattle breeds is highly recommended. Finally, the creation and regular updated repositories and genomic databases for Beninese and African AnGR will support adequate AnGR monitoring, enabling further advances through meta-analyses and collaborative studies [134].

3.1.3. Structured Interventions with Appropriate Farmer and Market Organizations

Clear structures and effective collaborations between different stakeholders are imperative for the organization and successful implementation of livestock improvement strategies [23,135]. Scientists have highlighted the importance of participative conception and execution of development programs with smallholders [18]. A real participation of farmers ensures effective consideration of their interests, needs, and expectations, the identification of real problems, and adequate on-herd solutions. Community-based breeding programs (CBBPs) have been proposed to promote farmers' indigenous knowledge, and ensure training, competence sharing, and institutional interventions [136,137]. CBBPs are focused on creating local interest in the management of AnGR and set up breeding and animal selection schemes within village herds [19,137]. Benin can valuably benefit from the developing expertise (in designing and implementing CBBPs) on the continent, especially in countries located in West Africa [19,137,138]. The sociocultural relationships within and between agro-pastoralists and mobile pastoralists promote the establishment of CBBPs in Benin [30,33]. For instance, the entrustment practice, where several cattle owners (generally the agro-pastoralists) place their animals under the management of a professional herder (i.e., the traditional pastoralist), is increasingly observed in Beninese pastoral areas [34,139,140]. A restructuring of existing entrusted cattle herds (gathering animals from several owners) may facilitate the establishment of village herd pools and farmer associations.

In addition to the organization of farmers in breeder associations, local operating teams that inspire trust and confidence to the participants are necessary. Marandure [18] suggested the training of young communal animal workers to support farmers, practice health services, or research activities, and to supervise the effective implementation of the respective tasks. In several pastoral villages in Benin, the participation of resident young people in breeding programs would be valuable to overcome language barriers and facilitate a good collaboration with other stakeholders. Finally, a proper breeding program design should focus on the development of local market niches, taking into account traditional structure and household organization around the management and commercialization of herd products. For instance, Chabi-Toko [117] described an organized milk management system that ensures domestic consumption, active participation of women, and fair sharing of resources among Beninese pastoralist households. This example indicates the need to involve women in cattle breeding strategies for extensive sociological and economic impacts. Moreover, the establishment of value chains that undermine the familial organization of livestock farming has very little chance of success. Evidence is the failure of recent development projects aimed at creating dairy units for gathering and processing milk from smallholders in Benin. Indeed, these dairy units are poorly supplied with milk, which does not ensure their effectiveness [141]. In addition, Beninese local milk producers are facing high competition due to imported industrial dairy products, indicating the need to develop innovative and adequate approaches for the promotion of the traditional Beninese dairy technologies and marketing [142]. Further strategies should also target the promotion of nonclassical sources of income for farmers (such as manure contracts and hiring of draught power), and the improvement of local markets with short and fair distribution systems between producers and consumers [18,143].

3.2. Breeding Programs

3.2.1. Conserving and Building on Local Cattle Genetic Resources

The long-term success of genetic improvement relies not only on the development of suitable breeds (or crossbreeds) for production but also on the maintenance of genetic diversity [20,119].

The genetic diversity within and between Beninese cattle breeds is an important asset for adaptability, sustainability, and cattle population fitness [31,144], and in consequence, is the basis for the environmental and economic viability of any improvement programs.

In this regard, the conservation of Beninese indigenous breeds is a priority and consists of addressing major threats (i.e., high mortality rate, uncontrolled crossbreeding, and decreasing interest in indigenous taurine cattle) that reduce effective population size and increase inbreeding. Genomic tools offer various possibilities to evaluate the livestock population structure (considering effective population size, admixture, and inbreeding rate), to identify major threats and to apply appropriate conservation strategies [145]. Recent investigations have outlined the opportunities to promote and conserve the Somba and Lagune breeds in vivo in cooperation with local farmers [33]. Similar examples for indigenous taurine cattle, including the Baoule or N'Dama, have been reported in other West African countries [19].

Conserving Beninese taurine breeds is also important to establish backup populations for ensuring continual access to pure genetic lines in crossbreeding programs [18]. Burrow [146] recommended a minimum of 25% to 75% of "adapted genes" in breeding programs to guarantee optimal production under challenging production systems. Similarly, Knap and Doeschl-Wilson [147] suggested a breeding strategy including resistant or tolerant local animals as a cost-effective alternative to improve productivity in tropical herds. In Benin, the Borgou crossbreed represents a convenient candidate to conciliate cattle productivity with adaptability [45,148]. The current adaptability of the breed and its acceptance by many Beninese farmers imply the necessity to identify admixture rates that suit farmer objectives, breeding systems, and environmental requirements [133,135]. Furthermore, improving Zebu animals may be an alternative for some traditional pastoralists, who are very attached to these animals. The White Fulani, a three-purpose (meat, milk, and draught) cattle breed, is a recommendable breed for enhancing cattle productivity in Benin. The broad distribution of Zebu across West Africa is a chance to develop collaborative research activities and breeding programs in the subregion. Finally, the introduction of exotic breeds other than West African local breeds should represent the last resort. The use of exotic animals for crossbreeding may be explored for specific production systems (such as intensive farms), capitalizing on their advanced genetic characterization and experiences from other African countries [21,22].

3.2.2. Targeting Selection for Robust Cattle

As presented above, smallholder breeding objectives encompass a large variety of traits related to animal production, reproduction, health, temperament, and efficiency in resource use. Previous selection signatures and genome-wide associations confirm the high genomic association between productive and adaptive traits in Beninese indigenous breeds [113,144]. Therefore, defining multicomponent breeding traits considering productivity, resilience, and adaptability (instead of classical specific productive traits) is recommended for the improvement of Beninese AnGR [149,150]. The holistic breeding approach to integrate the production ability of an animal with its physiological and immunological response to environmental challenges (reaction to stress, health, feeding efficiency, etc.) is conceptualized as robustness [150,151]. A robust animal is able to produce efficiently (i.e., to maintain high performances or breeding values under variable stressors) [118,150]. The novel traits indicating robustness that are being increasingly developed in controlled dairy systems should be evaluated in the context of Beninese extensive cattle systems [124,152]. For instance, Calus et al. [152] associated robustness in dairy cattle with diverse traits (body condition, milk composition, milkability, calving interval, temperament, mastitis, and feet and leg conformations).

Moreover, advances in genomic selection contribute to enhancement of the genetic-statistical model for the estimation of variance components and breeding values considering genotype by environment interaction (G × E) [151]. In this regard, reaction norm models have been applied, studying the environmental sensitivity of a trait (e.g., productive performance) across an environmental descriptor gradient [153]. The high variability and instability of production systems and environments under Beninese conditions chal-

lenge the evaluation of G × E. However, the collection of repetitive and large-scale environmental data and the definition of suitable herd environment descriptors (such as production level, farm size, or composition, disease pressure, and reproduction management) support the investigation of G × E in a challenging production context, as observed in South Africa [150,154,155]. Furthermore, statistical Bayesian and GBLUP models adapted to small datasets enable genomic selection to achieve substantial genetic gain within a relatively short time frame for developing countries like Benin [156].

3.2.3. Improving Farmer Management Practices

Although animal selection and breeding schemes are supposed to fit local conditions and management systems, the practices of farmers need to be upgraded. Smallholders mainly expect aid from researchers or policymakers that addresses improved utilization of feed resources and the management of animal diseases. Food security and control of diseases are considered the foundation of any durable improvement in animal productivity [157]. However, the greatest attraction to avoid is the promotion of externally sourced commercial feed and veterinary inputs, being cost-prohibitive and not permanently affordable to smallholders [18].

Here too, it is important to draw on endogenous knowledge and practices to propose solutions that are accessible and easily adoptable by breeders. For instance, crop–livestock integration is described as an imperative and promising agro-ecological system to support the reduction of feed shortage and management of rangelands [158,159]. This practice is well known and has been practiced for decades in Benin. Additionally, the crop–cattle association at the household level, and manure contracts (where cattle herders exploit crop residues from other crop farmers in exchange for manure) are described in Beninese agro-pastoral areas [28,47]. The exploitation of manure is interesting in managing nutrient flows for increasing soil fertility and rangeland production [160,161]. These practices should be assessed and valorized considering previous scientific recommendations [158,162]. For the management of rangelands and water sources, various pastoralist initiatives, including better distribution of grazing areas, reorganization of herd mobility, and combination with further adaptive management practices, have been described as promising and sustainable in Cameroon [163,164]. Such initiatives should be advocated over systematic eradication of herd mobility and fodder cultivation by individual herders, which is hardly feasible in the context of land competition and difficult access to land resources by pastoralists in Benin [165]. Regarding disease prevention and treatment, traditional farming practices should be similarly supported and enhanced by scientific investigations [107]. The improvement of traditional methods for disease control associated with an improvement in the management of animal housing and feeding, as well as the breeding of resistant animals are the most sustainable solutions to avoid drug resistance and guarantee animal food quality [166].

3.2.4. Promoting Institutional Supports

The management of AnGR and improvement of cattle production are only sustainable when clear national livestock development policies, adequate institutional frameworks, relevant scientific research activities, and durable technical and financial resources are in place [17]. National authorities have the first responsibility to create appropriate sociological and legislative environments, allowing farmers to securely practice their activities and be promoted by national and international institutions or development organizations. In Benin, recent reforms have addressed the regulation of national and regional cattle mobility, as well as land use policies. However, a larger consultation with scientists and smallholders (crop farmers and livestock keepers) is required to ensure the effective and fair access of rural actors, especially pastoralists and agro-pastoralists, to pastoral resources (rangelands and watering points) [167]. Simultaneously, governmental agricultural services are expected to strengthen their interventions in rural areas. In addition, political commitment to provide incentives for scientific innovation is imperative. This

implies financial support and facilities for scientific interventions [7,162]. There is a critical need to reinforce university training (especially in animal breeding and genomics) and reorganize research and development initiatives in a way that they can benefit national policies for improving the livelihoods of farmers [134]. Good scientific cooperation is fundamental to set a national research agenda oriented toward the identification of sustainable livestock development solutions. So far, collaboration between Beninese researchers has been limited, while researchers from various backgrounds (animal breeders, geneticists, system analysts, and IT specialists) are expected to develop overall data collection strategies. Datasets from different disciplines have provided an extensive comprehension of the production system and characterize the different resources involved in livestock production (AnGR, rangelands, and water sources) [18,123]. Finally, bilateral partnerships with regional and international universities and institutions will be valuable to create opportunities for the exchange of knowledge and technical resources and to enhance capacity building and research qualities. For instance, the International Livestock Research Institute (ILRI) has significantly contributed to the improvement of AnGR and livestock production in countries in eastern Africa. Such institutional supports are lacking in West Africa, especially in French-speaking countries, as the *Centre International de Recherche-Développement sur l'Élevage en Zone Subhumide* (CIRDES) entitled to support livestock production in these countries has been less dedicated to the management of AnGR [23].

4. Conclusions

Extensive cattle production has a great potential to significantly contribute to food security and enhance the livelihood of smallholders in Benin. However, the lack of adequate breeding strategies, scientific investigations, and political and financial supports is a severe constraint in a challenging environmental context including feed shortage and disease pressures. We reviewed various opportunities applicable in the current Beninese context to improve the management of local AnGR for sustainable development of low-input cattle production. We showed that appropriate strategies should be based on the breeding objectives of farmers. In addition, the adaptation of recent advances in IT, genomic applications, and statistical analyses to local conditions will help to assess the potential of indigenous AnGR and implement appropriate breeding schemes for local production systems and environmental constraints. The enhancement of local scientific and technical capacities, effective involvement of farmers in research studies, and political commitments are fundamental for durable progress. Furthermore, assistance from regional and international organizations, as well as collaboration with international scientists or research institutions, would be very valuable.

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