Feature Article

Development of genetically improved tropical-adapted dairy cattle

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Implications

- Limited animal production undersupplies animal-sourced foods to populations in tropical regions while improving local productivity promotes food security and livelihoods.
- Strategically exploring traits of interest from distinct genetic groups is a valuable tool to promote the sustainability of livestock systems.
- Genetic improvement of animals requires well-structured programs to avoid the opposite effect.
- When developing these programs, a broad approach should be considered that ideally accommodates the local necessities and conditions where they are being implemented.

Key words: *Bos indicus*, *Bos taurus*, climate, crossbred, Girolando, tropical-adapted

Introduction

According to recent estimates, about 80% of cattle reside in tropical or subtropical regions (Cooke et al., 2020a). The number of farmers and consumers, as well as overall production (e.g., annual milk production), is also greater in the tropics. However, cattle productivity in these regions is underwhelming compared with most temperate zones characterized by high-input farming practices and yields correlated with the fitness of the breeds to their system. Furthermore, it results from the adverse conditions derived from the underprivileged economic, social, and climatic conditions of the region (Oosting et al., 2014). Therefore, although livestock activity is broadly represented in the tropics, many challenges must be overcome to achieve sustainable production systems that meet this crucial demand, mostly among low-income smallholders.

According to the World Bank (World-Bank, 2007), the necessity for increased productivity in the tropics arises from three different demands. One of them is the insufficient availability of animal-sourced foods decreasing protein and essential nutrients (i.e., vitamin B-12 and fatty acids) supplies, which are predominant elements of undernutrition (Guiné et al., 2021). It also results from environmentally unsustainable animal production practices, inappropriate land use, and its influence on climate change. Finally, the state of deficient livelihoods, as many people rely on farming exclusively. The aspects mentioned above are englobed in a sustainable food system (SFS), described by FAO (2018) as "a food system that delivers food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition for future generations are not compromised," which relates to a universal approach to food security matters.

There are several prospects for promoting SFS, and excellent results are described by the introduction of straightforward management practices. For example, Oosting et al. (2014) separated dairy cattle feed into ten classes, "1" being greatest quality and "10" being least quality, to compare herd performance. Overall, offering a greater-quality ration improves the average milk production per animal, reducing methane emissions per kilogram of milk. However, the greatest quality ration offer did not yield optimal herd milk, probably because the diet failed to meet the distinct requirements of the animal. Their findings suggest a critical relationship between genetic characteristics and nutritional value and amount of feed, supported by O'Neill et al. (2010) that describes the "complex interactions between genotype, environment, and management (G × E × M)" and its connection with the performance of an animal.

To supply this demand, our research group and collaborators are developing genetics focusing on particular environmental conditions in locations within the tropics. We aim to introduce more efficient animals, develop and promote progressive farming techniques, optimizing the positive effects described in the previous paragraph, as well as other production

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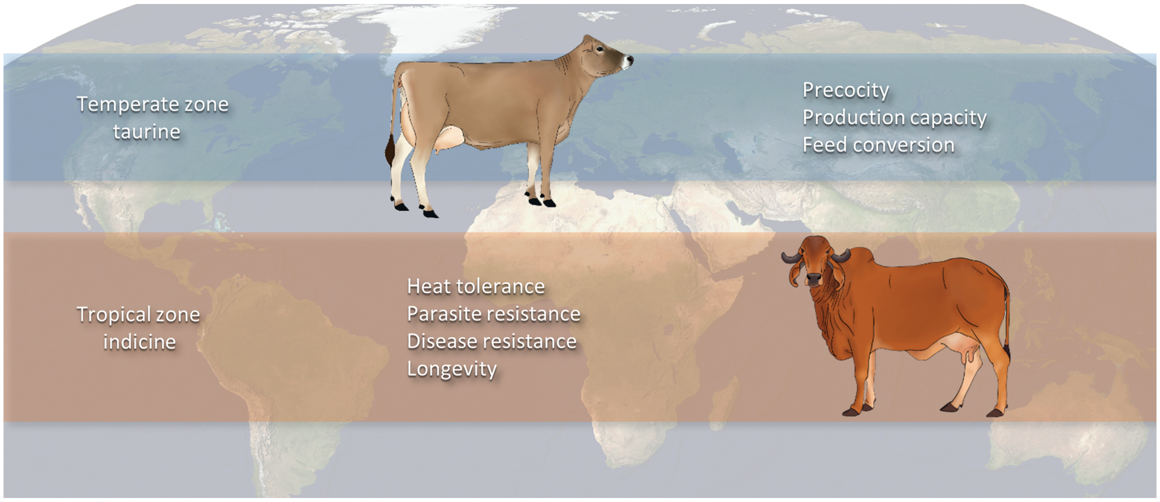

Figure 1. Representation of *B. taurus* (taurine) and *B. indicus* (indicine) cattle. Associated to their corresponding climatic and geographic regions of origin and traits of interest for tropical-adapted cattle crossbreeding. Background map courtesy of https://ian.macky.net/pat/license.html.

traits. We will establish these herds based on the strategic exploration of traits of interest identified in different cattle genetic groups (*Bos taurus* and *Bos indicus*). This strategy has shown excellent production potential in the tropics (Cooke et al., 2020b; Vieira et al., 2022). Distinct breeds will be utilized, primarily focusing on dairy but likely expanding to the beef sector, using a similar approach, addressing the needs of smallholder farmers. The project emphasizes nutrition and livelihood improvement mainly by increasing animal-sourced food availability and the income of the farmer through more sustainable livestock systems. However, besides food supply, food security relies on adequate regulatory measures and political consistency (Guiné et al., 2021), the ultimate components of the panorama of the project.

Bos taurus and Bos indicus

Bos taurus taurus has been naturally selected and evolved to suit the temperate climate. In addition, as they were raised and selected by different social groups, breeds diverged to distinct body sizes (large and medium) and purposes (dairy, beef, dual purpose). Some examples of taurine cattle of different sizes and aptitudes are Charolais (large, beef), Jersey (medium, dairy), and Normande (medium, dual purpose). In addition to these local conditions, the evolution of their traits is marked by global industrialization, which increases the demand for animal-origin products. Therefore, these modern breeds have undergone extensive artificial selection and controlled breeding practices, targeting greater production capacity phenotypes (O'Neill et al., 2010). Inevitably, it increased inbreeding levels (Purfield et al., 2012) and the incidence of undesired recessive alleles, resulting in detrimental effects on functional traits like fitness, longevity, and reproduction (Rauw et al., 1998). For these reasons, current breeding programs are coordinated using genotypic information to deviate from it. European taurines are animals with high input, excellent production capacity, and high susceptibility to stressors of the tropics.

Unlike taurines, *B. taurus indicus* cattle, originally from India (Naik, 1978), evolved from tropical and more challenging environments, acquiring unique endurance characteristics. As a result, they present an increased capacity for maintaining body temperature in high heat conditions and overcoming parasite challenges. In addition, a reduced metabolism and maintenance requirement added to the ability in digesting inferior quality fodders (Hunter and Siebert, 1985). These traits allow them to sustain their performance (e.g., reduced pregnancy loss) even under restricted nutritional conditions (Fontes et al., 2019). *B. indicus* animals are called indicine, humped, or zebu cattle and represent about 75 breeds, for example, Gir, Guzerat, Kangayam, and Nelore. Currently, because of indicine suitability to stressful environments, these breeds have spread around subtropical and tropical countries for beef, dairy, and draft purposes (Turner, 1980; Madalena, 2002). However, they show limited productive potential even after artificial selection, compared with taurine animals under optimal conditions (Turner, 1980).

Tropical-adapted animals

In tropical conditions, taurine cattle are more susceptible to diseases and metabolic disorders, failing to express their productive potential while indicine cattle are not able to sustain satisfactory production. However, as the subspecies evolved, they acquired particular traits of interest as tropical-adapted livestock (Figure 1). While *B. taurus* show high production potential (beef and dairy), feed conversion efficiency, and reduced age at first calving, *B. indicus* have greater longevity and high heat, disease, and parasite resistance. When combined, these traits generate the ideal tropical-adapted animal. Widespread crossbreeding of *B. taurus* and *B. indicus* cattle is a valuable strategy to accomplish that.

The descendants of purebred crosses are expected to perform better than their ascendants because of the separation of unfavorable alleles (Sørensen et al., 2008). Additionally, the more distinct the parental breeds are, the more significant the heterosis or hybrid vigor impact, which is the case of *B. taurus* × *B. indicus*. The hybrid vigor influence is predominantly detected in health, longevity, and reproduction. However, it will also affect advantageous genetic arrangements observed in the founder breeds (Falconer and Mackay, 1996). Hence, for successful crossbreeding results, a tactical determination of breeds and genes of interest is critical, besides an extensive application of genomic information to guide purposeful matings.

A few of the composite/synthetic dairy breeds that were developed by crossbreeding *B. taurus* and *B. indicus* breeds are listed in Table 1.

As previously mentioned, the objective of the breeding programs was to produce offspring that would carry the relative strengths of the *B. taurus* and *B. indicus* founder breeds. Development of composite breeds was no easy task, sometimes consuming many decades. Nevertheless, in the successfully concluded programs, the crossbreds manifested the desired traits. On the one hand, they exhibited superior milk production and fertility traits compared with their *B. indicus* ancestors. On the other hand, compared with their *B. taurus* ancestors, they showed superior heat tolerance and parasite resistance in the tropics. For example, AMZ and AFS cows have often produced in excess of 6,000 liters/lactation under tropical Australian conditions. This milk production is more than double the typical lactation yields of their *B. indicus* ancestors. Tick resistance among crossbreds has also been reported (e.g., number of ticks on crossbreds was <10% of that in purebred taurines; Madalena, 2002).

Unfortunately, in many crossbreds, F2 and F3 generations did not perform as well as their parents (F1). For example, in Thailand, Malaysia, and India, these crossbreds failed to produce more than 2,000 liters/lactation (Clarke and Sivasupramaniam, 1983; Umpaphol et al., 2001). According to some studies, the F2 generation also performed poorly with certain reproductive traits like *age at first calving* and *calving interval* compared with the F1 generation (Syrstad, 1989; McDowell et al., 1996). Reviewing the *status quo* of each composite breed is beyond the scope of this article. However, one point needs to be emphasized; many of these crossbreeding programs have ceased functioning today. Underlying reasons are numerous, underperforming offspring being an obvious one. Going against the grain, one composite breed in particular, namely the Girolando, has risen above the rest and flourished, particularly in Brazil. The hybrid has succeeded so much in Brazil that in 2021, about 80% of the total milk production of the country's 35 billion liters (IBGE, 2021) came from Holstein × Gyr crossbreds (Silva et al., 2022).

The first crossbreeding happened over 80 years ago in Brazil. Soon, many farmers started adopting this strategy, and extension programs developed. However, progeny testing began only in the 1990s, through joint efforts of the Brazilian Association of Girolando Breeders and Brazilian Agricultural Research Corporation (Embrapa). Later, these companies implemented the Program of Genetic Improvement of Girolando (PMGG) for a more resourceful and embracing approach. The program aims to detect and propagate outstanding genetics to stimulate Brazilian dairy sector sustainability. As a result, in 20 years (2000–2021), a 63% increase (3,695 kg to 6,032 kg) is reported for the average production of a Girolando in 305 days (Silva et al., 2022). Nowadays, Brazil is the fifth largest milk producer in the world (FAO, 2021).

The achievements of the Girolando project arise from well-established strategies and intensive efforts. According to Silva et al. (2022), the PMGG collects and processes genotypic, phenotypic, and pedigree data from thousands of local farms. It uses molecular markers to identify alleles of interest in milk production, like volume, protein profile, fat content, and genetically inherited disorders. In addition, it develops and applies several analyses and indexes for morphological, reproductive, and productive characteristics, such as Girolando Tropical Efficiency Index (IETG), which incorporates information about animal longevity and heat stress tolerance (Silva et al., 2022). Moreover, the index categorizes animals by their capacity to sustain productivity in tropical conditions. Considering all these available tools, farmers can assertively select and maintain efficient animals in their herds and plan for strategic matings.

Girolando cattle comprises animals of distinct genetic groups according to the proportions of the founder breeds (H (dam) × G (sire)). For example, 1/4H, representing a bovine that is 1/4H, 3/4G, and other common assemblies like 3/8H, 1/2H, 5/8H, 3/4H, and 7/8H. Although the heterozygosis effect is present in all cross levels, they may present distinct

Table 1. Dairy Composite Breeds that were previously developed by crossbreeding *B. indicus* and *B. taurus* breeds

Composite breed	*B. indicus* founder breed	*B. taurus* founder breed
Girolando	Gir (also spelled Gyr)	Holstein Friesian
Australian Friesian Sahiwal (AFS)	Sahiwal	Holstein Friesian
Brazilian Milking Hybrid (BMH)	Gir and Guzerat	Holstein Friesian
Jamaica Hope	Sahiwal	Holstein Friesian and Jersey
Australian Milking Zebu (AMZ)	Sahiwal, Red Sindhi	Jersey
Sunandini	Nondescript zebu cattle	Holstein Friesian, Jersey, and Brown Swiss
Mambi de Cuba & Siboney de Cuba	Cuban zebu	Holstein Friesian

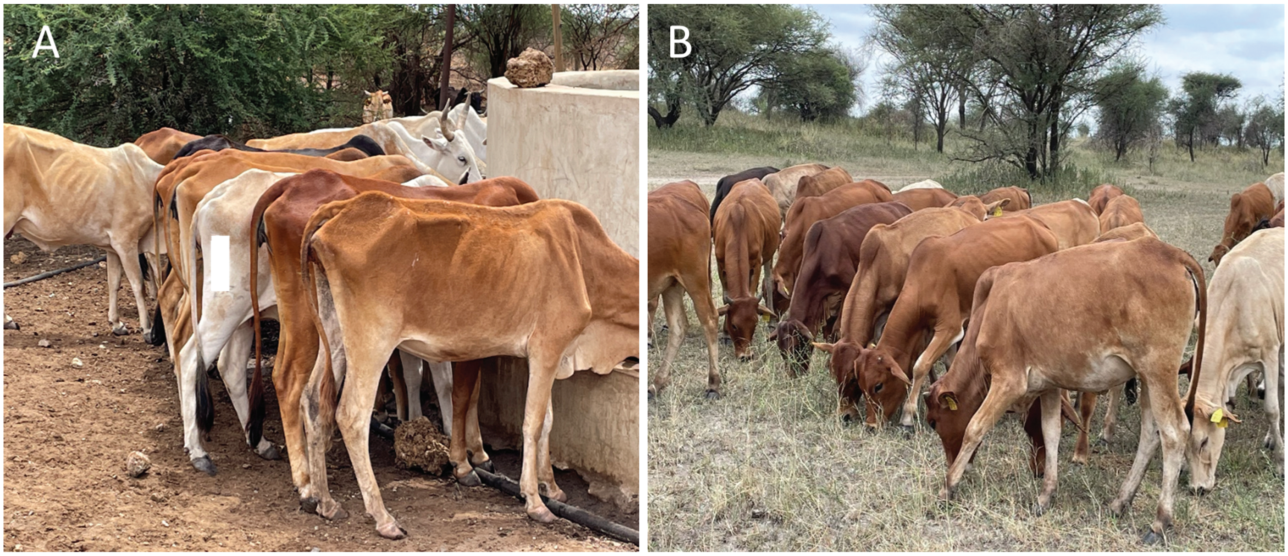

Figure 2. Pictures of a native cattle breed in Northern Tanzania, representing the impact of the season (Panel A—dry season body condition, Panel B—rainy season body condition) on the body conditions of these animals. Photos courtesy of Crystal Allen and Moeses Ole-Neselle.

attributes and responses to environmental conditions. Vieira et al. (2022) analyzed records from 1,221 Girolando herds in southeast Brazil (tropical Atlantic climate) composed of different Holstein and Gyr proportions. They found that 1/2H, 3/4H, and 7/8H animals perform similarly better in production and reproduction than 1/4H and 3/8H. Corroborating with these findings, da Costa et al. (2015), comparing 1/2H and 3/4H in northeast Brazil (semiarid climate), reported similar productive performance for both groups. However, for reproductive and physiological variables, there was a significant difference during the dry season, where 1/2H was more successful in overcoming climate stressors. Overall, having available Girolando crosses with their particularities brings versatility in meeting the demand from the dairy systems. These findings reinforce the idea of livestock performance as a result of genotype, environment, and management interaction, a key part of the University of Illinois project, further described in this review.

University of Illinois Tropical-Adapted Cattle Project–Tanzania

Rationale

Tanzania has diverse domestic Animal Genetic Resources (AnGR) essential for economic development and enhanced livelihood. It is estimated that the livestock sector contributes about 6.9% to the GDP, of which 40% comes from beef, 30% from dairy, and the remaining 30% (2.07%) from other livestock sub-sectors such as poultry, small ruminants, and pig production (URT, 2022). In addition to its share to the GDP, the livestock sector is critical to the economy of the country and the well-being of particularly the rural population. Livestock has multiple roles in the livelihood strategies of rural communities. In many communities, livestock is intricately linked to social status through the accumulation of wealth and savings. It also benefits rural communities in terms of risk mitigation, food security, and improved nutrition.

Despite the critical role of livestock for economic development in Tanzania, growth in livestock productivity has been below that of other developing regions. The contribution of the livestock industry to the Agricultural Gross Domestic Product is relatively low (~7.1%) (Asimwe, 2022). This contribution is mainly due to low livestock growth rates, feed scarcity, and high mortality rates due to drought (Figure 2), disease, poor reproductive performance, and poor quality of the final products. Modest improvements of these production coefficients coupled with value addition through processing could significantly increase output and income from the livestock industry.

Long-term observations of ecological drivers and rangelands health in Northern Tanzania have demonstrated the following, 1) delayed, short, and heavy rainfalls affecting groundcover resulting in more frequent drought due to surface running water being a common phenomenon in Northern Tanzania rangelands and 2) fragmented and degraded rangelands due to overgrazing, incompatible land use practices (Wiethase et al., 2023), and unrealistic national programs on land use plans (USAID, 2022). As a result, a drought is now an event that makes current management challenges faced by livestock producers even more difficult than previously when there was more pasture and water available.

In the future, rainfall has been projected to decrease and temperature to rise by 3.4°C in 2100 (IFRC, 2022). The frequency of unusual short-term droughts has been widespread in recent years (IFRC, 2022). The climate outlook for November 2021 to April 2022 indicated that during the wet season, rain was below normal in many regions of Tanzania, resulting in prolonged dry periods. By December 2021, the situation was worse than expected, resulting in a severe shortage of pasture and water for livestock. More than 60,000 animals died during this period (IFRC, 2022). To mitigate this extreme situation, farmers migrated and concentrated livestock in better grazing areas many kilometers from their homes. Further, they used family food stocks to feed their livestock and their resources to buy animal feed, impacting the family economy (IFRC, 2022). In response to the local and international demand for animal products, the United Republic of Tanzania has established a 5-year program (2022–2027) addressing issues in the agricultural and rural sectors. The measures for livestock improvement involve the implementation of more tolerant (to drought, flood, and disease) forage varieties, the promotion of livestock and crop integration, and the development of information systems for the management of climate-related risks (IFAD, 2022).

Most of the cattle raising and herding in Tanzania are done by the Maasai people who inhabit much of the country. The Maasai people of Tanzania are a semi-nomadic ethnic group known for their distinctive customs and traditions, which revolve around livestock husbandry and pastoralism (Århem, 1989). The Maasai cattle complex is a term coined by development practitioners and government entities in the early 1960s to describe the interdependent relationship between the Maasai people and their cattle in East Africa, mostly in Tanzania. According to van der Meer et al. (2015), the Maasai cattle complex originates from the central role of cattle in Maasai culture, being highly valued for their economic, social, and cultural significance. They provide the Maasai with milk, meat, blood, and hides and serve as a currency, status symbol, and religious icon.

In addition to their practical uses, cattle are a source of cultural pride and identity for the Maasai. This cattle complex is also characterized by the intimate knowledge of the Maasai of the natural environment in which they live (Homewood and Rodgers, 1991). They deeply understand the land and its resources and have developed sustainable grazing and land use practices that allow them to coexist with wildlife and other indigenous communities. It is a testament to their resilience and adaptability in the face of changing social, economic, and environmental conditions (Homewood and Rodgers, 1991).

One unique aspect of Maasai culture is their preference for specific livestock colors. For example, reddish-brown and blackish are the two major colors of cattle under Tanzania Shorthorn Zebu (TSHZ) (Homewood and Rodgers, 1991). The colors are highly prized among the Maasai clans, which fall into two major clans: Mollel and Laizer. The colors are a symbol of health, prosperity, and social status (Homewood and Rodgers, 1991). Therefore, considering this color preference, *in vitro*-fertilized (IVF) embryos derived from Jersey × Gyr and Holstein × Gyr have been produced at the University of Illinois for the livestock genetic improvement project. The next step is to transfer these embryos to local Tanzania Shorthorn Zebu (TSHZ) recipient cows in late 2023 or early 2024, producing calves with the genetic potential to increase local productivity, precocity, and household income.

Description of the project

For many years, the authors have worked with cattle in tropical regions, including Brazil, Panama, Costa Rica, Honduras, and the Dominican Republic (1997). In the spring of 2017, a project was developed to produce a high-health status Girolando herd that could undergo genetic selection to improve dairy and beef production in tropical climates like Tanzania. This project is designed to establish nucleus herds of specific cattle breeds (Gyr, Gyr × Holstein, Gyr × Jersey crosses, Angus × Zebu) to evaluate, select and deploy animals with improved milk or beef production to feed hungry people in the developing world. To achieve and sustain maximum genetic gains from the Tropical-Adapted Cattle Project at the University of Illinois, the proposed genotypes, either dairy (Holstein × Gyr) or beef (Angus × Brahman or Zebu), are being evaluated for performance (milk production or meat production) [phenotype] and this information correlated with the genomic index [genotype]. Reference populations were established on partner cattle farms located in the southeastern United States to gather the necessary data in a controlled manner.

Elements of the project

This project is multi-faceted. It involves 1) development of infrastructure including assistance with the design and development of farm facilities; 2) production of the reference population(s) including the development of breed specific nucleus herds as necessary (Gyr, Angus, Brahman, Girolando); 3) collection of phenotypic data (e.g., birth weight, milk production, weaning weight, etc.) as required to correlate with the genomic evaluations; 4) testing of reference population(s) for genomic traits; 5) identification of the "best" donor and sire combinations to produce the IVF embryos for distribution to developing countries; 6) distribution of the resulting embryos to appropriate recipients in developing countries to establish pregnancies and produce live offspring; 7) provide education and training to local veterinary professionals, farm managers, and even producers in assisted reproduction techniques (artificial insemination, IVF, Embryo transfer) so the improved genetics can be propagated and sustained; 8) provide assistance to the developing countries in order to establish a national strategy for the continued genetic improvement of livestock to help ensure food and income security; 9) provide assistance with commodity marketing and private sector involvement to ensure sustainability and food security for the local communities, and 10) feeding hungry children.

The project completed year 5 of the breeding program in 2022. We had access to a few Gyr cows but plenty of Gyr semen. Therefore, we produced only some high genetic potential pure Gyr and hundreds of Girolando (1/2H, 3/4H, 5/8H, and pure synthetic [5/8 H × 5/8 H]) heifers, cows, and bulls, using a combination of Holstein donors, F1s, and F2s. Initial lactation data with 1/2 H (n = 5) showed milk production of 18–25 liters per day over two lactations. The animals were maintained exclusively on pasture in a hot (32–33°C) and humid (90%) environment. We started the project with 40 donor females and produced 369 calves by IVF (Figure 3) from 2018 to 2021. We produced 53 calves from 13 donors in 2018, 91 from 20 donors in 2019, and 105 from 21 donors in 2020 *(Covid-19 year)*. We produced 456 calves in 2022 from IVF and natural service.

There were several issues that we addressed scientifically during this project. These challenges mainly relate to the reproductive biology of *B. taurus* × *B. indicus* crosses which has not been thoroughly characterized. These crosses show significant variation in estrous cycle patterns. Because of the time required to produce the five-generation crosses, we wanted to make as many IVF embryos as quickly and efficiently as possible. We decided to use ultrasound-guided ovum pick-up (OPU) as we had limited donors due to the lack of a large population of Gyr cattle in the United States.

As this was a crossbreeding study, we first established our population of Holstein donors *in vitro* embryo production rates. We had previously decided not to use super stimulation of the donors and to collect oocytes from the follicular population present on the OPU day. A greater number of total and viable oocytes were retrieved from lactating cows than from heifers. Both conventional (non-gender selected) and sexed (gender sorted) semen were used in this study. The results showed that conventional semen produced more embryos in heifers than sexed semen. Still, there was no difference between the two semen types in lactating cows (Silva et al., 2019). Further, oocytes from lactating Holstein donors seem more suitable for *in vitro* embryo production than oocytes from Holstein heifers (Silva et al., 2019).

As estrus manifestation was a potential issue with these Holstein × Gyr crossbred females, we examined the relationship between estrus and pregnancy rates in synchronized recipient cows (Pasqual et al., 2020). There was no statistical difference in pregnancy per embryo transfer (P/ET) rate between the estrus detection groups. The conclusion was that all recipients that showed estrus from 36 to 96 h post-CIDR removal could be used as recipients in an ET program with IVF embryos without impacting the P/ET rate (Pasqual et al., 2020).

During our OPU program, we observed a highly variable number of oocytes recovered between and within our donor cattle. Dominant follicle removal (DFR) in *B. taurus* cattle has improved oocyte quality and number. However, the effects of DFR in half-blood *B. taurus* and *B. indicus* cattle were undocumented. Therefore, three studies were designed to determine whether we could improve the number and quality of oocytes recovered from randomly cycling Holstein × Gyr crossbred cattle (Long et al., 2021; Marchioretto et al., 2021; Rabel et al., 2023). The overall hypothesis was that removing the dominant follicle before OPU would increase the number and quality of the oocytes recovered. The authors concluded that using DFR before OPU, specifically 48 h in advance, was beneficial in ½ *B. taurus* (Holstein) × ½ *B. indicus* (Gyr) crossbred cattle, resulting in greater-quality oocytes (Long et al., 2021; Marchioretto et al., 2021). A third study confirmed that the optimum time for OPU in ¼ Holstein × ¾ Gyr crossbreds is ~48 h after rather than ~72 h post-DFR (Rabel et al., 2023). Additional studies with all the possible Holstein × Gyr cross combinations are necessary to determine the effects of DFR on oocyte quantity, quality, and embryo development in these *B. taurus* × *B. indicus* crossbreds.

Conclusion

In this review, we approached the promotion of food security in the tropics by implementing programs that focus on livestock suitability to be productive in these areas. This strategy is greatly associated with crossbreeding and using assisted reproductive technologies to optimize and accelerate livestock productivity gain. It shows potential for upgrading the efficiency of animals in the tropics with ample scientific information that can support these accomplishments. However, their application must be carefully planned and executed, especially under complex resource-limited conditions, like those in the tropics. Furthermore, the main concern seems to be having these technologies oriented and refined to meet local demands. Therefore, we have started our project by improving the reproductive performance of our herds by understanding their

Figure 3. Herd developed in the southeastern United States using commercial recipient cows (accessible and of no genetic interest for the project), allowing the transfer of IVF embryos for the fastest production of genetically superior lineages. Photos courtesy of Marcello Rubessa and Sarah Womack.

particularities and establishing protocols that better fit them. In addition, we will supply these genetics, predominantly using embryo transfer and artificial insemination, matching the conditions of the farms we will be working with.

We believe in the importance of these embracing pilot projects that, in this case, have the genetic improvement of herds as the core to livestock productivity increase. Following the introduction of target genetics, the programs will cover region-specific educational and management aspects. This broad approach will set the standard for the animals to express their potential fully. Furthermore, as the project progresses, we would ideally have more involvement from the respective governments that would incorporate these programs. As alliances are established, public policies would be developed supporting this framework, allowing its refinement and organized expansion, reaching neighbor communities and regions, and stimulating other countries to adopt similar approaches. Ultimately, sustainable food security will be promoted in these areas by consistently addressing aspects discussed in this review.

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Moses Ole-Neselle is an experienced veterinary surgeon trained Maasai from northern Tanzania with vast knowledge of livestock production in the tropics. He is a livestock development specialist with extensive experience in participatory training programs development, participatory Research Methods/Techniques, and project design and planning. He is well known for critical strengths in participatory planning, organizational team building and individual capacity building, and supporting institutional capacity building. Dr. Ole-Neselle is of crucial interest, seeing that the tropical livestock breed from Tanzania has improved potential to contribute to nutrition and food security for the respective livestock-producing communities known as “pastoralists.” To achieve this Ole-Neselle facilitated and supported field teams to undertake field-based research and participatory rural assessments (P.R.A.) and local community engagement to adopt new scientific breakthroughs for livestock production.

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