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COMMISSION ON GENETIC RESOURCES FOR FOOD AND AGRICULTURE

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DRAFT STUDY ON THE ESTABLISHMENT AND SCALING-UP OF BREEDING PROGRAMMES IN CHALLENGING ENVIRONMENTS

Note by the Secretariat

1. In endorsing the outline of *The Third Report on The State of the World's Animal Genetic Resources for Food and Agriculture* (Third Report) at its Nineteenth Regular Session, [1] the Commission on Genetic Resources for Food and Agriculture (Commission) approved, subject to the availability of the necessary resources, the coverage of "special topics", including: (i) vulnerability of animal genetic resources in the face of climate change and the role of genetic diversity in adaptation and resilience; (ii) establishment and scaling-up of breeding programmes in challenging environments; and (iii) genomic measures of genetic variation and the future use of the breed concept in the formation of new breeds. The Twelfth Session of the Intergovernmental Technical Working Group on Animal Genetic Resources for Food and Agriculture has also suggested addressing the topics of gene editing and other emerging technologies, if possible.[2]

2. In response to these recommendations, FAO commissioned the preparation of thematic studies covering the three topics approved by the Commission, as well as on genome editing and emerging technologies in animal phenotyping, as suggested by the Working Group. These studies are at various stages of development and will be made available online for commenting by countries along with sections of the draft Third Report.

3. FAO utilized extra-budgetary funds from the Government of Germany to contract with the National Research Institute for Agriculture, Food and Environment, Paris, France (INRAE) to convene an expert group to undertake the study on *Establishing and scaling-up of breeding programmes in challenging environments*. This document summarizes the study. The document has been prepared by Florence Phocas (Université Paris-Saclay, INRAE, AgroParisTech, GABI, Jouy-en-Josas, France); Jean-Luc Gourdine (INRAE, Petit-Bourg (Guadeloupe), France); Hélène Gilbert (INRAE, Toulouse, France);Vincent Ducrocq (Université Paris-Saclay, INRAE, AgroParisTech, GABI, Jouy-en-Josas, France); Jérome Raoul (Institut de l'élevage, département de génétique, Castanet Tolosan, France, and GenPhySE, Université de Toulouse, INRAE, ENVT, 31326, Castanet Tolosan, France); Maria Wurzinger (BOKU-University of Natural Resources and Life Sciences, Vienna, Austria, and Iowa

[1] CGRFA-19/23/Report, paragaph 107.
[2] CGRFA/WG-AnGR-11/21/Report, paragraph 21.

State University, Ames, United States of America); and FAO staff members. The content of the review is entirely the responsibility of the authors and does not necessarily represent the views of FAO or its Members.

DRAFT STUDY ON ESTABLISHING AND SCALING UP BREEDING PROGRAMMES IN CHALLENGING ENVIRONMENTS

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Breeding programmes (BPs) are systematic efforts aimed at improving livestock. There is a wide variety of options for their design and implementation. Breeding programmes involving either centralized nucleus schemes and/or imports of exotic germplasm for crossbreeding are most often unsustainable in low-income countries. There are exceptions for some intensive or semi-intensive production systems in peri-urban areas (Philipsson et al., 2006; Kosgey et al., 2006). Community-based breeding programmes (CBBPs) have emerged in the last two decades as workable alternatives to jointly conserve and improve local breeds, at least for local small ruminants in Africa (Haile et al., 2023), Asia (Bhuiyan et al. 2017; Gowane et al., 2019) and Latin America (Mueller et al., 2015). A characteristic of these CBBPs is that locally adapted breeds are to be improved and therefore dependence on external input is reduced. Important features are the livestock keepers' active participation, from design to implementation and the consideration of locally available infrastructure and support options (Mueller et al, 2015). These CBBPs have been promoted as a tool for the economic and livelihood development of smallholder farmers in low-input systems through genetic improvement of livestock.

This sub-chapter aims at identifying levers to develop livestock BPs under challenging conditions (harsh environments, difficult market access…), targeting specifically smallholder farms in low-input and extensive systems. Therefore, special attention is paid to CBBPs. Novel information was collected from interviews of stakeholders (national and international research organisations, public and private breeding institutions, NGOs) across countries in Africa, Asia, Latin America and the Caribbean and completed with information from the literature (see part A). The interviews aimed at gaining insights into the structure of the respective BPs, animal numbers, information flows and decision-making, as well as external factors (legal environment, policies, financial support, competition, networks and partnerships). The 17 gathered case studies shed light on successes and failures by examining stakeholders' motivations, institutional and financial support, and farmers/breeders' organisation involvement and choice of breeding goals and strategies (see part B). Evaluation of the BP efficiency or inefficiency (see part C) is accompanied by recommendations for an improved assessment of BP impacts (see part D). Finally, an analysis of key factors contributing to success or failure offers valuable insights into the factors shaping the outcomes of breeding programmes, paving the way for potential success stories (see part E).

A- General description of the case studies

The focus is primarily on CBBPs and low-input extensive systems (Table 1). The 17 case studies were either BP descriptions from interviews (n=9) or CBBP examples (n=8) from the literature (Mueller et al., 2015). The various case studies include a diversity of livestock species (i.e. chicken, small ruminants, cattle, Buffalo, pig, llamas) and products (i.e. meat, milk, eggs, wool and cashmere) coming from different regions (i.e. Africa, Asia, Latin America and the Caribbean). This section gives a general description of the case studies.

Case study 1. Development of poultry breeding for meat and egg production in Burkina Faso: two initiatives in link with an animal breeding company

Hendrix Genetics (https://www.hendrix-genetics.com) provides genetic lines of slow-growing broilers and dual-purpose breeds (meat and eggs) that are better suited to the tropical conditions compared to standard commercial broilers. These lines help smallholder farmers to get higher egg production and heavier chickens than local breeds. The company is involved in two projects focused on implementing BPs: i) The “Poulet du Faso” BP aiming at producing crossbred chickens from locally selected sire line ‘Coq du Faso’ and slow-growth SASSO hens (https://europe.sasso-poultry.com) and ii) the sustainable access to poultry parent stock to Africa (SAPPSA) project aiming at securing access to SASSO parent stock and at testing dual purposes lines under African conditions. These two BPs started with 5 years programmes supported by the Bill and Melinda Gates Foundation (BMGF) and are described in detail in Annex 1.

Case study 2. Development of poultry meat and egg production in Ethiopia

In Ethiopia, Ethiochicken (https://www.ethiochicken.com/) is a private company ~~solely~~ dedicated to providing improved chicks to smallholder farmers. Since 2010, this company has become one of the leading distributors of day-old chicks in the country. The company has well-equipped breeding farms and hatcheries in Ethiopia, and it is the primary African customer for SASSO-Hendrix Genetics dual-purpose breeds (see case study 1). It supplies approximately 46 million-day-old chicks (SASSO-Hendrix genetics) annually to 8 million small-scale farmers. At 5 weeks old, the chicks are sold primarily to smallholders (ranging from 20 to 100 chickens).

Case study 3. Development of CBBPs for local sheep breeds in Ethiopia

The Ethiopian CBBP for sheep production have been launched in eight communities with distinct sheep breeds (Afar, Bonga, Horro and Menz) and production systems. The aim of the project was to develop BPs adapted to community conditions and farmers' needs, in order to improve the productivity and income of these smallholder farmers. The core of the project has been to organize community members to work together on performance recording, selection, management and utilization of rams (Mueller et al., 2015).

Case study 4. Development of sheep BP in Kenya

The Red Maasai and Dorper sheep BPs and crossbreeding initiative were established in 2003 at the ILRI (https://www.ilri.org/) ranch in Machakos County. The primary goals were to enhance the productivity and profitability of sheep raised in low-input systems in Kenya's arid and semi-arid regions by combining the faster growth rate and higher meat production of the Dorper breed with the resilience of the Red Maasai breed. Additionally, the BP aims to sustainably conserve purebred Red Maasai sheep through selection for growth, adaptability, and resistance to *Haemonchus contortus*. This BP is described in detail in Annex 2.

Case study 5. Development of a dairy goat CBBP in Kenya

In 1995, the CBBP implemented by the NGO FARM-Africa (https://www.farmafrica.org/) aimed to enhance milk production and growth rates of indigenous East African goats by crossbreeding with Toggenburg dairy goats. Farmers technically trained received 4 purebred Toggenburg females and one male on credit, creating a breeding unit, altogether establishing a dispersed nucleus. The popularity of the project producing crossbred goats led to a strong demand for breeding stock, causing goat prices to increase fivefold. But breeders often succumbed to the temptation to sell their best young goats rather than keep them for breeding, resulting in negative selection for growth rate (Mueller et al., 2015).

Case study 6. Development of dairy Cattle and Buffalo BPs in India

In India, smallholders raise cows and buffaloes primarily on crop by-products and residues. Crossbreeding by artificial insemination of *Bos indicus* animals (zebu) with exotic *Bos taurus* has resulted in 30 to 35 million crossbred cows, predominantly Holstein or Jersey crosses with indigenous breeds like Gir, Sahiwal, Kankrej, Gujarat, and Rati. Details of the BPs are given in Annex 3. The current goals are to develop an appropriate BP for the existing population of crossbreds and to stabilize and standardize sustainable programmes for all breeds. The development of genomic selection led to the creation of two (currently separate) Bos taurus x Bos Indicus crossbred populations 1/ at the National Dairy Development Board (https://www.nddb.coop/) and 2/ at the BAIF Development and Research Foundation (https://baif.org.in/) which benefits from a collaboration with BMGF. Both organisations are producing very large amounts of frozen semen (including sorted semen) delivered to scattered smallholder farmers in most Indian states through a large network of AI technicians with motorbike.

Case study 7. Development of small ruminants BPs in India: a goat governmental BP vs. a CBBP

These two BPs are described in detail in Annex 4. Since the 1990s, the governmental breeding project has focused on improving local goat breeds. Coordinated by the Indian Council of Agricultural Research (https://icar.org.in/), this “All India” breeding programme involves over 20 research centres and encompasses 15 to 18 different goat breeds. However, data management has not been centralized despite several attempts by the Indian Council of Agricultural Research. The program collaborates with numerous breeders who raise goats for their livelihood. The Nimbkar Agricultural Research Institute (https://nariphaltan.org/), NARI, the only NGO involved in this programme, has managed records for the Osmanabadi goat breed in Maharashtra. NARI is also technically supporting a CBBP, initiated in 2018 by the Aga Khan Foundation (https://the.akdn/en/home) and funded for five years by BMGF. The CBBP involves approximately 50,000 black Bengal goat keepers in Bihar state. NARI is registering the animals in around 16 villages across four blocks in the Muzaffarpur district. This programme utilizes a cloud-based database where farmers can input and access data at any time. Male kids selected by NARI are used as breeding males, with these males being purchased by women from other villages. Currently, about a hundred breeding bucks are used for natural service.

Case study 8. Development of a cashmere goat CBBP in Iran

The CBBP aims to enhance cashmere production to improve the livelihoods of smallholder farmers and rural women involved in exporting cashmere, wool, and mohair. Initiated through discussions with nomads, local authorities, and extension agents in 2009, the CBBP was implemented in 2010. In the Baft region of

Kerman province, nomadic extended families collectively raise herds of Raeini goats for meat and cashmere. The programme has established eight nucleus herds, each consisting of the 40 highest-quality female goats and the two best males, selected based on fleece weight, laboratory-assessed cashmere quality, colour, and body size. These nucleus animals are bred separately from the base animals, which are kept in small corrals or separate pastures during the breeding season. Annually, the lower-performing male in each nucleus herd is replaced by a more successful young male to maintain and improve the quality of the herd (Mueller et al., 2015).

Case study 9. Development of a local broiler BP in Thailand

In Thailand, most chickens are derived from parent and grandparent stock imported from the United States and the United Kingdom. In response to food security concerns, challenges faced by smallholder farms, and the loss of native genetic resources, Suranaree University of Technology (https://www.sut.ac.th/en/), SUT, the Department of Livestock Development (https://dld.go.th/th/index.php/th/), and the Thailand Research Fund (https://fundit.fr/en/institutions/thailand-research-fund-trf) decided to collaborate on developing a native meat-type crossbred chicken line a decade ago. SUT selected a productive female line and crossbred it with the native “Leung Hang Khow” breed, as this crossbreeding results in chickens with yellow skin and shanks—traits preferred by Thai consumers. This crossbred line was named Korat chicken. The initial breeding objective focused on enhancing meat texture and flavour while maintaining competitive production costs. Currently, selection efforts are concentrated on improving feed conversion ratio and meat texture to boost smallholder farmers' income. This BP is presented in Annex 5.

Case study 10. Development of a CBBP for local pigs in Vietnam

This pig CBBP was initiated by a research and development project (2000-2014) involving local smallholder farmers in the province of Son La in northern Vietnam, and stimulated by local, district, provincial, and national government entities. Project evaluations were conducted collaboratively by researchers from the national research institute, farmers, and government representatives using participatory approaches. The research results led to the implementation of a CBBP aiming at the profitable marketing of high-quality pork products from local breeds. Stable technical cooperation with farmers has been established over the years, building on existing communal organisational structures. Responsibilities are shared within a local breeding and marketing cooperative. Contracts have been signed with an industrial partner. The project has successfully adapted conventional BP to continuously evolving conditions, ensuring ongoing improvements and sustainability of the CBBP (Mueller et al., 2015).

Case study 11. Development of a CBBP for Angora goat in Argentina

In the northeast of the Patagonian Desert, around 3,000 farmers manage approximately half a million Angora goats using low-input systems. Thirty years ago, rural extension officers established a breeding nucleus at an institutional research farm to address the issue of low fleece weights by selecting high-quality animals from different communities. Communities were asked to choose flocks as multipliers, which would receive bucks from the nucleus and produce breeding males for the rest of the community. Over time, the multipliers became independent and operated as multiple linked CBBPs. However, the structure weakened due to low Mohair prices and the lack of price incentives for superior fibre. In 1998, the 'Argentine Mohair Program' (SAGPyA 2000) was established to improve farmer livelihoods by enhancing fibre quality and implementing a new marketing strategy while maintaining the BP. By 2008, the programme included 13 organisations with 835 members and eight institutions. A dispersed nucleus was formed with nine flocks and 71 multipliers. Participants in the programme achieved 40–100% higher prices than non-participants.

However, the increasing number of involved communities led to organisational challenges and reduced control over the CBBP (Mueller et al., 2015).

Case study 12. Development of a CBBP for llama in Bolivia

The CBBP was established in several stages. The project commenced with an in-depth analysis of the llama production system in the Ayopaya region of Bolivia. Following this, a local NGO partnered with research institutions to create a legally recognized producer organisation. Connections were made with fibre processors and marketing organisations, and a market quality requirements study was conducted. An animal identification and performance testing system, along with a mating centre, were established. A two-stage selection procedure was planned, with the top males kept at the mating centre during the breeding season, allowing community members to bring their female llamas for mating. Despite these efforts, several challenges hindered the project's implementation after the research phase. These included extremely difficult logistical conditions, institutional and political instability, mistrust among stakeholders, lack of external funding, and the inability to establish a solid commercial link. Consequently, the project could not be fully realized (Muller et al., 2015).

Case study 13. Development of BPs for dairy cattle in Brazil

The dairy industry is characterized by small (9% of herds with less than 10 ha and 10 cows) and medium-size farms (39% of herds with 10 to 100 ha). Small dairy farmers and some medium farmers mainly produce for their own subsistence. The use of artificial insemination (AI) remains limited in the Brazilian dairy industry (10% of cows bred using AI) compared to the Brazilian beef industry (~20%). The Guzera and Gir dairy breeds, originating from India, are the most widely used for milk production in Brazil's tropical and subtropical regions. In the 1980s, several initiatives were undertaken to enhance milk production in these areas, including the promotion of Holstein x Gir crosses (such as the synthetic Girolando breed) and Holstein x Guzera crosses. This initiative facilitated the creation of public-private partnerships with breeders' associations, such as the Brazilian Zebu Breeders' Association, the Brazilian Association of Gir Leiteiro Breeds, and the Brazilian Association of Girolando Breeds, all under the supervision of the Ministry of Agriculture. The Brazilian Dairy Gir BP was established in 1985 through a partnership between the Brazilian Agricultural Research Corporation (https://www.embrapa.br/en/international), Embrapa, and the Brazilian Dairy Breeders Association. In 1994, the Brazilian Center for Guzera Genetic Improvement, in collaboration with Embrapa-Dairy Cattle, launched the National Programme for improving Guzera Dairy Production. This programme utilizes both a progeny testing system and a Multiple Ovulation and Embryo Transfer nucleus system. These BPs are described in detail in Annex 6.

Case study 14. Development of a BP for pig in Haïti

The BP began in 1986, initiated by the French Ministry of Agriculture, Natural Resources and Rural Development, and the French Minister for Cooperation. Its goal was to provide small farmers with rustic pigs following the eradication of the local Creole pig population due to a massive African swine fever epidemic in the late 1970s. The rustic pig population was reconstituted using a maternal line (a cross between Chinese Meishan or Jiaxing breeds and the local French Gascon breed) and a paternal line of Guadeloupe Creole pigs. The program was launched with a primary breeding centre (PCS) at Thomassin, where the lines were established and maintained. Secondary multiplication centres (CMS), run by NGOs or the project, were set up to distribute the pigs. Farmers' organisations and individual farmers purchased and bred the crossbred animals. After an interruption from 1991 to 1994, a new project supported by the International Development Bank, the French Cooperation, and the European Union was launched to re-establish the CMS, train farmers at PCS, and develop a complete pig production system involving all value chain stakeholders The program faced significant challenges, including communication issues, feeding difficulties, and a new outbreak of African swine fever in 1996, which prioritized sanitary measures over genetic improvement. Despite these setbacks, by 1998, 43% of pig multiplication came from PCS, with the remaining 57% from 15 CMS, 12 of which had formal contracts with the project promoters. This BP is described in detail in Annex 7.

Case study 15. Development of a CBBP for dairy goats in Mexico

Participatory workshops in 2007 revealed that farmers were dissatisfied with exotic bucks and identified the lack of breeding local bucks as the main limiting factor. In response, ten farmers from one community agreed to launch a CBBP. With support from a team of national and international researchers they established organisational and administrative rules for the CBBP. A milk recording system was implemented, and the farmers agreed to take young males from the best dams to a test station for growth performance evaluation. The cooperation mechanisms were adapted over time to better meet the farmers' needs (e.g., sharing of feeding costs for performance testing between national research institution INIFAP and farmers). Even after the end of the research project, the CBBP continued to operate and expanded to neighbouring communities. Long-term commitment of the research team has been a crucial factor in the sustainability of the CBBP (Muller et al., 2015).

Case study 16. Development of a CBBP for sheep in Peru

Three types of sheep production systems have been observed in the highlands of the Sierra Central: individual family flocks, communal flocks without breeding plans, and multi-community flocks managed by cooperatives grouping together several villages. In 1995, after in-depth discussions within the communities, the village leaders decided to develop an efficient livestock structure. Participating villages contributed land and manpower to create a central nucleus, while the National University of La Molina in Lima provided technical support. The nucleus was formed by crossing imported and local superior rams with 50 of the best females from each of the nine communal and multicommunal flocks. The offspring of local rams proved more profitable overall than those of imported rams, which only improved wool quality. The CBBP was managed by the "Society of Corriedale Breeders of Cerro de Pasco" and has attracted new members (Muller et al., 2015).

Case study 17. Development of BPs for sheep in Uruguay

In Uruguay, each sheep breed has its own association, and all these associations are members of ARU (Asociación Rural del Uruguay). Since 2002, genetic evaluations have been carried out by INIA, the Uruguay's National Agricultural Research Institute (http://www.inia.uy/en), in collaboration with various institutes and private organisations. These evaluations cover various breeds, whether specialized in wool, meat or dual-purpose. Breeding objectives are defined collectively at participatory workshops attended by all stakeholders. Numerous traits are currently recorded on farm and/or at INIA facilities (e.g. faecal egg count, foot rot, reproductive traits, feed consumption and methane emission). Breeders are responsible for supplying data to the official genetic database. Additional data are provided by laboratories (wool quality) or by INIA (ultrasound measurements, feed efficiency, CH_4 emissions). Details of these BPs are given in Annex 8.

Table 1. List of the 17 case studies

Region	Country (interview or review[1])	Species	Main product	Key references
Africa	1. Burkina Faso (interview)	Chicken	Meat (Egg)	Duijvesteijn et al. (2022)
	2. Ethiopia (interview)	Chicken	Meat (Egg)	Markos et al. (2016)
	3. Ethiopia (review)	Sheep	Meat	Duguma et al. (2011), Haile et al. (2019)
	4. Kenya (interview)	Sheep	Meat	Oyieng et al. (2022)
	5. Kenya (review)	Goat	Milk	Ojango et al. (2010)
Asia	6. India (interview)	Cattle & Buffalo	Milk	Ducrocq et al. (2018), Al Kalaldeh et al. (2021)
	7. India (interview)	Sheep & Goat	Meat	https://nariphaltan.org/suwarna.pdf
	8. Iran (review)	Goat	Cashmere	Mueller (2013)
	9. Thailand (interview)	Chicken	Meat	Poompramun et al. (2021)
	10. Vietnam (review)	Pig	Meat	Roessler et al. (2012)
Latin America and the Caribbean	11. Argentina (review)	Goat	Mohair	Mueller (2013)
	12. Bolivia (review)	Llamas	Fiber	Wurzinger et al. (2008)
	13. Brazil (interview)	Cattle	Milk	Madalena et al. (2012)
	14. Haïti (interview)	Pig	Meat	https://agritrop.cirad.fr/311103/1/ID311103.pdf
	15. Mexico (review)	Goat	Milk	Wurzinger et al. (2013)
	16. Peru (review)	Sheep	Wool	Mueller (2013)
	17. Uruguay (interview)	Sheep	Meat (Wool)	Ciappesoni et al. (2013)

[1] the review case studies have been taken from Mueller et al. (2015)

B- Establishing a breeding programme

Developing sustainable and efficient breeding programs (BPs) requires considerable efforts, even though the theoretical framework for establishing breeding strategies suited for challenging environments has been firmly established for years, as reviewed in the operational framework for assisting countries with breeding guidelines from FAO (2010). Specific guidelines for establishing community-based breeding programs (CBBP) focused on small ruminants have also been provided by Haile et al. (2019).

This section highlights successes and failures drawn from insights collected through the 17 case studies (Table 1). The case studies aimed at gaining insights into the structure of the respective BPs, numbers of animals involved, information flows and decision-making, as well as external factors (legal environment, policies, financial support, competition, networks and partnerships).

1. Who are the stakeholders and what are their motivations and incentives for starting a breeding programme?

We adapted the table proposed by FAO (2015) to identify the most important stakeholders at the local level (Table 2). The stakeholders' motivations can vary depending on the context and the objectives of the BP. One of the essential motivations is to improve income of farmers/livestock keepers. Other aspects such as research and innovation play a minor role. Nevertheless, whatever the context, it is essential that the diverse stakeholders' interplay to ensure the success of the BP and its sustainability, as their views, expertise and resources help to shape breeding objectives, strategies and outcomes.

The BP development necessitates close collaboration with the livestock keepers' community directly involved in and impacted by its implementation. This ensures the formulation of tailored breeding goals and strategies that align with the specific needs and aspirations of the community. Breeding goals encompass diverse traits, such as productivity (e.g. weight in most cases but also amount of milk or eggs, litter size or fibre/wool production depending on species and breeds/lines), cultural values (for instance cockfighting skill) or aesthetic preferences like the colour or the morphology (for instance the "bicycle" morphology type of the 'Coq du Faso' chicken in Burkina Faso, see Annex 1, the yellow skin of the Korat chicken in Thailand, see Annex 5, or the dark colour of the Creole pig breed in Haiti, see Annex 7), and adaptative traits (e.g. disease resistance and heat tolerance of the Red Masai sheep breed in Kenya, see Annex 2).

The analysed BPs, including CBBPs, have been primarily initiated by research institutions (all cases, except case 1 described in part A) and/or involved support by non-governmental local organisations (NGOs. They have also sometimes involved national governments in conjunction with local institutional support (cases 3, 6,7, 8, 10, 11, 13, 14). The livestock keepers' involvement is crucial for initiating and implementing any CBBP, even when the degree of their involvement may greatly vary from one case to another. The implementation of CBBPs combines genetic improvement programmes with infrastructure, deep social links within the community involved in the programme, and market development (Mueller et al., 2015).

An astonishing example concerns Brazil (see Annex 6) that stands out in both global beef and dairy cattle production with a total of 234 million cattle and 2.5 million farms (IBGE, 2022). However, the Brazilian situation is extremely contrasted between the beef and dairy sectors. While the beef cattle supply chain has undergone technological modernisation in its production systems with large private investment in biotechnologies, nutrition, health and welfare practices since the 1990s, resulting in a large beef international export market, and expectations that Brazil will probably be a major exporter of beef (Nelore) cattle genetics by 2040 (Malafaia et al., 2021), the dairy industry has only few resources to invest in technology (such as high-quality semen of improved bulls) as there is almost no export market and limited demand in Brazil for high-quality fresh milk. However, there are some interesting Brazilian BPs under development for tropical zebu breeds, but they do not seem to be oriented towards livelihood improvement of smallholder farmers.

The organisational structure of BPs is influenced by the nature of its stakeholders and the type of financial backing it receives (see part C). External or national funds have always been injected at least for the first years of a starting BP and most CBBPs still depend on external funding sources (except cases 4, 14) and on technical support, both external and national (all cases). National incentives have frequently been applied only for a while. For instance, the International Livestock Research Institute (ILRI) had to stop the support to the Kenyan sheep CBBP (case 4, Annex 2) when the COVID pandemia started in 2020. However the sheep CBBPs in Ethiopia (case 3) have and still received technical and financial support from CGIAR-canters (Haile et al., 2023). In India, a large part of the agriculture policy aims to directly support farming (cases 6 and 7). It is a structural commitment (not only towards farmers, but covering everything related to livestock, plants, cooperatives, semen production) of the Indian Council of Agricultural Research and its numerous Institutes owned and managed by the government of India. Provincial governments also own and maintain their own agriculture, animal science and veterinary science universities. There is no consultative process: decisions go from top to bottom in India. When external funds help to promote some initiatives such as the chicken projects in Burkina Faso (case 1, Annex 1), the continuation of the projects appears dependent on the motivations of governments or private enterprises to provide a prolonged technical or financial support to the emerging BPs. For instance, the chicken projects in Burkina Faso (case 1, Annex 1) started with 5 years programmes supported by BMGF that paid for the facilities, rearing and production farms of the selection centre 'Coq du Faso', as well as for the running costs for the first 5 years of the local BP. Now these subsidies are no longer available. The farmers' cooperative is not really making profit, but it is self-sufficient and pays all costs for animals and salaries. The involvement of Hendrix Genetics to pay for the recurrent test of SASSO lines (SAPSSA project) in the Burkinabe selection centre allows to get some funds for investment in the cooperative.

2. Choice of the genetic resources and breeding schemes

The choice of genetic resources (breeds/lines) and breeding schemes (pure-breeding, cross-breeding, creation of a synthetic breed…) varies according to the species and numerous local considerations, including the cultural or heritage significance of indigenous/local breeds, their production purposes (for subsistence or for sale), their economic competitiveness (linked with their performance) in comparison to imported exotic breeds/lines, and the financial resources available for conservation and/or genetic improvement.

For instance, only local breeds are involved in the Ethiopian CBBPs (case 3) for sheep (Afar, Menz, Horro or Bonga breeds). In India, a large part of the milk comes from *Bos indicus* cows and local buffalo breeds (such as Murrah, Surti, Jaffarabadi, …), and also from crossbred dairy cattle, where exotic *Bos taurus* breeds such as Holstein Friesian or Jersey are crossed with local Zebu breeds such as Gir, Sahiwal, Kankrej and Gujerat, which benefit from their natural adaptation to harsh conditions. Following the same reasoning, in Brazil, Zebu breeds used for dairy production initially originated from India (case 13, Annex 6). For chicken in Burkina Fasso, male lines are local breeds used to cross with either SASSO hens to produce the 'Poulet du Faso' crossbred (case 1, Annex 1) or with hens from Suranaree University of Technology (case 9, Annex 5) in Thailand to produce the 'Korat' chicken, combining morphological and adaptation characteristics of the males to production potential of the females. Another interesting example was the creation of lines during the replacement of the Creole pig in Haiti after its eradication in 1981 due to the African Swine fever crisis. The porcine population was replaced by maternal animals issued from a cross between Chinese Meishan and Jiaxing breeds with French Gascon, sired with males from a Creole Caribbean breed from a neighbour island (Guadeloupe), to achieve relatively prolific heat-tolerant pigs relying on poor feeding resources, with the morphological characteristics of the original local breed (black pigs, case 14, Annex 7). Even when structured dissemination of improved animals is organized, crossbred animals between the improved local type and exotic improved breeds can be found in most of these countries, not originally planned but contributing to food security and farmers´ livelihood too.

3. Development of the breeding programme

Implementing a BP requires a combination of local and scientific knowledge. Particularly, BP implementation necessitates simultaneous efforts in breed conservation and improvement. A fair sharing of investments and incomes among stakeholders is also necessary. This entails enhancing the capacity of involved organisations to facilitate community-based management.

It involves education and training about breeding schemes, fostering collective participation to devise methods for conservation, production, and genetic improvement of collectively selected traits, while ensuring that techniques are accessible to farmers of varying literacy levels.

Various constraints must be addressed to efficiently implement a BP, including infrastructure and technology availability, market dynamics, and existing local agricultural and educational policies. For instance, in Uruguay, sheep breeding is managed by the National Agricultural Research Institute (INIA) in collaboration with private organisations, such as the Uruguayan Wool Secretariat for wool-oriented sheep (case 17, Annex 8). Fundamental aspects of implementing a BP are designing a comprehensive assessment of desired breeding goals, establishing robust data management protocols (facilitating efficient recording, storage and processing of information), and designing breeding strategies including mating plans. Considering the constraints related to infrastructure, availability of technology, and market dynamics, the breeding scheme necessitates adjustment to local conditions to ensure its successful implementation. As pointed out by Getachew et al (2022), every BP, including CBBP, experiences successive stages of improvement and adaptation. Monitoring a breeding programme is constantly needed. Actions can be taken to adapt or improve to new conditions (e.g., what are the challenges when a scaling process is started?). An increased number of farmers require a different management and decision-making strategy. A group of farmers (committee) might then make some of the decisions as not all aspects can always be discussed with the large group: these representatives have to be elected in an agreed way. Selection in CBBP usually relies initially on phenotypic performance, overlooking individual relationships.

If pedigree and performance data are collected, genetic evaluation models such as the pedigree BLUP animal model can be implemented as it is currently the case for 'Coq du Faso' chicken line in Burkina Faso (case 1, Annex 1), sheep in Uruguay (case 17, Annex 8) or for cattle in Brazil (case 13, Annex 6), even genomic models may be implemented as in cattle in India (case 6, Annex 3).

Table 2. List of stakeholders

	Case studies																
Stakeholders	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Government			X			X	X			X			X	X			
Research organisations			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Individual breeders / livestock keepers		X	X	X	X	X	X		X	X				X			
Breeders' associations or cooperatives	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
National commercial companies							X			X							
External commercial companies	X					X	X		X					X			
Non-Governmental organisations	X		X	X	X	X	X				X	X		X			
Public sector			X			X	X		X	X	X		X	X			X
Private sector						X	X		X	X			X	X			X

1.Burkina Faso (Chicken); 2. Ethiopia (Chicken); 3. Ethiopia (Sheep); 4. Kenya (Sheep); 5. Kenya (Dairy goat); 6. India (Cattle and Buffalo); 7. India (Sheep and goat); 8. Iran (Goat); 9. Thailand (Chicken); 10. Vietnam (Pig); 11. Argentina (goat); 12. Bolivia (Lamas); 13. Brazil (Dairy cattle); 14. Haïti (pig); 15. Mexico (dairy goat); 16. Peru (Sheep); 17. Uruguay (sheep)

Table 3. Choice of the breeds/lines

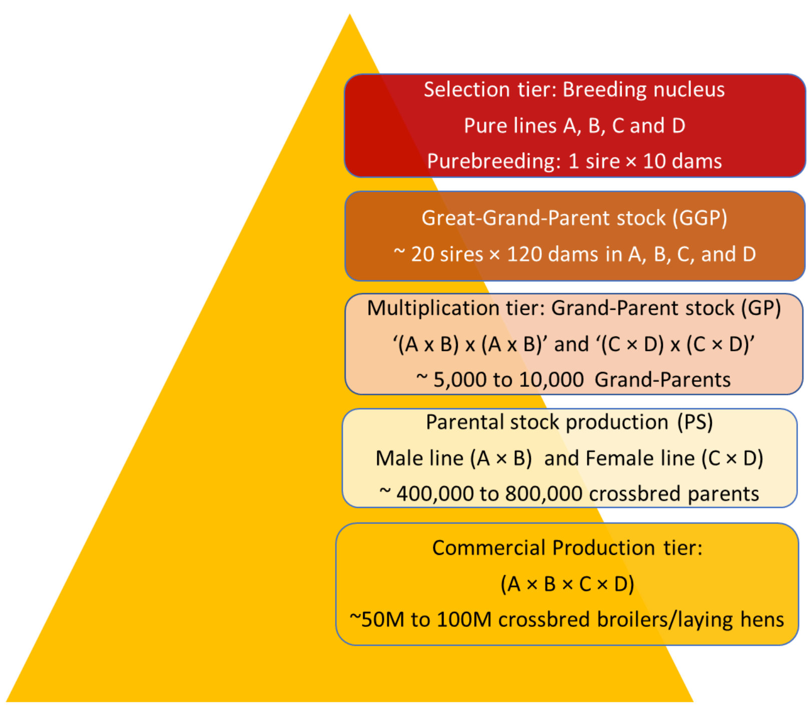
	Case studies																
Genotype	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Local breeds	X		X	X	X	X	X	X	X	X		X	X		X	X	X
Import of highly selected breeds for performance		X			X	X				X			X	X			X
Import breeds adapted to/selected for “challenging environment”				X							X		X	X			X
Crossbred	X	X		X	X	X			X	X			X	X			X
Synthetic lines									X				X				X

1.Burkina Faso (Chicken); 2. Ethiopia (Chicken); 3. Ethiopia (Sheep); 4. Kenya (Sheep); 5. Kenya (Dairy goat); 6. India (Cattle and Buffalo); 7. India (Sheep and goat); 8. Iran (Goat); 9. Thailand (Chicken); 10. Vietnam (Pig); 11. Argentina (goat); 12. Bolivia (Lamas); 13. Brazil (Dairy cattle); 14. Haïti (pig); 15. Mexico (dairy goat); 16. Peru (Sheep); 17. Uruguay (sheep)

4. Dissemination of genetic improvement from the selection tier to the production tier

The final step of a successful BP is the dissemination of improved genetic resources (animals or semen in case of AI) to farmers, so that the general level of the population improves. The dissemination of the genetic improvement is straightforward for terminal crossbred strategies, such as those applied in pigs in Haiti and poultry in Africa and Thailand. Key to the poultry BP success is the sustainable link between each part of the supply and value chain. In Thailand (case 9), 600 000 Korat chicks are produced every year in the SUT farm and sold to the farmers when they are 1 day old. Every Friday, farmers can come to SUT to get these 1-day old chicks, spreading genetic progress to about 400 smallholder broiler farmers who can rear 100 to 1000 Korat chicken. Similarly, African distribution companies (cases 1 and 2) use the parental stock (see Figure 1) to produce 1-day-old chicks which are sold to upper-level units with trained staff, which grow the 1-day-old chicks to 4-week-old teen chicks sold to smaller-scale farmers. In Ethiopia, Ethiochicken (case 2) is a private company with an exclusive focus on serving smallholder farmers with improved chicks. It currently serves about 46 million 1-day-old chickens (SASSO-Hendrix genetics) to 8 million smallholder farmers in Ethiopia on a yearly basis. Here also, most of the day-old chicks go to units whose staff is trained and receive technical support from Ethiochicken agents (for instance if mortality is too high, they get advice for management improvement). At 5-weeks of age, chicks are sold at a fixed price decided by Ethiochicken, mainly to smallholder farmers (from 20 to 100 chickens). In pigs in Haiti (case 14), a single nucleus farm was setup to select paternal and maternal lines and sell improved maternal crossbred dams and purebred sires to multiplier farmers. These farmers produced terminal crossbred piglets that were sold to smallholder farmers. However, these dissemination centres suffered from heterogeneous supplies and poor availability of quality feed, together with disease issues, which could jeopardize their performance and sustainability over time, whereas the nucleus farm was relatively protected from these issues due to subsidies.

Figure 1. A standard pyramidal breeding programme in poultry



For ruminants, in Latin America, multipliers are not well defined and the proportion of improved genes going to commercial production farms is not precisely known. Breeders disseminate genetic improvement through rams and bulls of their elite flocks that are sold to producers for natural service (see case 13 for Brazilian dairy cattle, Annex 6). Part of the dissemination, particularly for beef cattle in Brazil, is carried out via artificial insemination. In Africa and Asia, dissemination of genetic improvement to smallholder farmers can be initiated from animals selected in experimental stations, such as the improved animals of the Red Masai breed by ILRI in Kenya (case 4, see Annex 2). The genetic dissemination beyond these farms is poorly documented and therefore difficult to quantify. However, experts indicate that dissemination occurs through the collective use of improved males for mating. For example, in the case of the CBBP for Black Bengal goats in India (case 7, see Annex 4), the improved males are initially used free of charge by the community for the first two matings. Subsequently, breeders, whether from within the village or from outside, can pay to use the male. This practice helps to disseminate genetic gains beyond the CBBP. The lack of a dedicated organisation for the dissemination of genetic improvement can be detrimental and lead to the decapitalization of the improved population (case 5 for Kenyan dairy bucks, see part C).

C- Evaluating economic, social and environmental impacts of the breeding programmes

Policymakers, in particular governments, donors and investors in general, need both *a priori* and *a posteriori* evaluations of breeding programmes to make investment decisions and to start or (dis-)continue investing in such programmes. To ensure effective monitoring and evaluation of a BP, the programme team should establish key indicators to measure progress towards achieving the BP outputs which can be easily documented, directly measured and assessed (e.g., number of improved/disseminated animals, average EBVs of the selected breeding stock…). Indicators should also be defined to assess whether the BP outputs effectively contribute to the desired long-term outcomes and impacts at the individual herd, household, and breeding organisation or community levels. It is crucial to develop appropriate tools and procedures for monitoring these indicators, including well-defined timelines for each indicator. This approach will enable accurate tracking of BP performance and facilitate informed decision-making throughout the BP implementation. The time needed for a BP implementation and its mature development typically exceeds NGO project durations and governmental ruling periods. Continued funding will depend on positive evaluations of the BPs.

As highlighted by Lamuno et al. (2018), an evaluation exercise is a learning opportunity that can help to improve the programme, and a relevant tool to demonstrate that livestock breeding is a sustainable intervention strategy. Formal monitoring and evaluation of breeding programmes must be based on some impact indicators. As shown in section A, BPs are developed at various levels – national, regional, community - based on organisational structures, such as universities, social enterprises, NGO's, farmers' cooperatives or private companies. As stated by FAO (2010), there may be important differences between the evaluation criteria that are relevant at each level. While strict economic criteria (profit, return on investment) are often the main indicators from the perspective of a company, broader socio-economic criteria are important from a community's point of view. From a national perspective, a range of policy criteria are useful as a country with functional national animal BPs strengthens its food security and provides job opportunities. Ideally, all criteria should be described and analysed in economic terms, i.e., based on cost-benefit analyses accounting for the genetic gains cumulated over generations and the dissemination of improved genes in the entire population. However, this may not always be possible because of the intangible nature of some inputs or outputs involved (cultural, ethical or social values), the difficulty of collecting the relevant information or the lack of human resources or expertise to perform the analyses. Therefore, BPs need to be evaluated not only in terms of formal economic indicators, but should also consider additional criteria allowing considerations of the less quantifiable inputs and outcomes such as active participation in decision-making processes or gender roles.

1. List of indicators

A general framework for socio-economical and technical evaluation of BPs was described by FAO (2010). Among the evaluation criteria summarized by FAO (2010), those specifically relevant for CBBPs were identified by Lamuno et al. (2018 who presented an evaluation framework for the assessment of performances, outputs and associated impacts of CBBPs which is divided into three domains: (1) evaluation of CBBP implementation, based on organizational and technical criteria; (2) monitoring of implementation outputs in order to evaluate genetic improvement at herd level and the resulting changes at the household level and in the community at large; and (3) evaluation of associated impacts on livelihoods of farmers and on the environment. We propose, for these three domains, operational criteria for smallholder BPs to identify the tangible impacts of sustainable breeding strategies, as suggested by Woolliams et al (2005).

Domain 1. Evaluation of BP implementation based on organizational and technical criteria

Criteria	Indicators/explanation
Agreement Documentation	• Initial and current motivations of the stakeholders • Clear documentation of ownership, roles and responsibilities of BP members with signed agreements and contracts between partners • Supporting funds and budget allocation • Monitoring information system on herd size, selection, mating and marketing events
Participation of farmers	• Constitution of farmers' groups with varying levels of participation in BP • Farmers' control over own or donated funds • Gender representation, roles and equity of distribution • Involvement of farmers in the choice of the implemented breeding objective
Production system and breeding goal definition	• Cultural and social values of the improved livestock • Contribution of the improved products to local food availability and diversity to overcome current nutritional deficiencies • Consideration given to additional products (manure, fuel, draught power) • Alignment with national and regional current and future policies • Assessment of other activities which may interfere with the BP • Availability of baseline data on production system to document changes over time
Pedigree and data recording plan	• Ability to identify animals, to trace and correct pedigree records with a back-up system • Recording of relevant traits in adequate format and frequency, with data quality control • Training and expertise of the staff who carry out recording in the field (farmers, field technicians), transmission to database and data curation
Estimation of breeding values (EBVs)	• Collected information used by farmers for breeding decisions • Breeding values estimated using a suitable model • EBVs information delivered to farmers on time and in understandable manner
Selection and mating decisions	• Available EBVs to be used to select animals • Timely selection of breeding candidates (e.g. before marketing events) • Efficient use for reproduction of the selected animals • Control inbreeding by selecting animals not too related to each other and by avoiding matings of related animals • Assessment of replacement rate and generation interval

Domain 2. Monitoring of outputs to assess the BP impact at herd, household and breeding organization levels

Criteria	Indicators/explanation
Herd level	• Numbers of improved animals produced and distributed • Increase in animal products • Evaluation of realized genetic gain
Household level	• Improvement in animal management • Increased food consumption of the family • Changes in income • Involvement in decision making • Capacity building, skills and perceptions (how farmers feel the BP has impacted their lives)
Breeding organization / Community level	• Number of farmers in BP • Number of extension staff • Education level and training of farmers and technicians • Control of animal health and product quality (quarantine, mortality, quality check) • Access to high-technology tools (communication, genotyping, image recording...)

Domain 3. Evaluation of outcomes on livelihoods of farmers and on the environment

Criteria	Indicators/explanation
Income, food security & assets acquisition	• More income through sales of improved livestock and livestock products • Use of income from BP to buy food stuff or to cover other household expenses and to acquire assets • Food security of household members has improved (e.g. number of days without food reduction, increase in food consumption) • Increased market demand for breeding animals • Gender-sensitive analysis of income distribution within the household
Economic sustainability & sensitivity to external factors	• Higher farm gross margin or profitability per household per year due to increased productivity • Savings, investment and access to credits to sustain and improve animal production • Revolving fund system in place to generate more income at community level • Added value of products • Better market access, expand markets and limitation of imports • Back-up to account for unexpected conditions such as epidemics or draught (e.g., genebanks) • Concerns with genotype-environment interactions for the production systems
Distribution of benefits	• Distribution of benefits among members of BP • Adoption rate of BP and dropout rate of participants over a given period of time • Cooperation with other breeding organizations • Dissemination of the improved genes to the commercial tier • Distribution of benefits among producers, retailers/market operators and consumers along the value chain • Rural development and employment
Environmental impacts	• Conservation of biodiversity through use of local breeds • Management of (communal) pastures to mitigate environmental degradation on soil and natural vegetation (decreasing or increasing the stocking rates) • Control measures in place to manage animal wastes and residual water • Carbon and water footprints of BP*

*FAO's Global Livestock Environmental Assessment Model (GLEAM) uses life cycle assessments to quantify GHG emissions generated along livestock supply chains. In: Global Livestock Environmental Assessment Model (GLEAM 3.0). https://www.fao.org/gleam/dashboard/en/

2. Qualify/quantify the impacts of the breeding programmes for the case studies

The following section presents the results of the analysis of the case studies using the framework (see above). The analysis is based on personal interviews with experts and literature findings. Due to the lack of data, only a partial analysis could be carried out. This demonstrates the difficulty of a comprehensive analysis, as in many cases the data is either not collected or is insufficient.

Only three indicators have been investigated and documented in all 17 case studies: the degree of farmers' involvement in the BPs, in particular in the definition of breeding goals, the choice of the breeds/lines, and the breeding strategy, i.e. pure breeding versus crossbreeding in centralized closed nucleus versus decentralized breeding systems (dispersed and open nucleus, all flocks). The main indicators of Domain 1 (see section C.1) could be documented either by literature or interviews in most case studies. This was not true for indicators of Domain 2, and even less true for Domain 3 indicators.

A systematic evaluation of BPs is needed, to assess the farmers' interests and willingness to work towards planned objectives and contribute to the programmes' sustainability. It should also be noticed that genomic tools have been used for a decade in some low-income countries to determine the breed composition, to verify parentage and coat color in some dairy cattle and sheep CBBPs (Mrode et al., 2016; Muniz et al., 2016), to operate genomic selection in some cattle breeds (Al Kalaldeh et al., 2021), or to test for the presence of a major gene such as the Booroola ('Fec B') gene in sheep. This gene was for instance introgressed from the Garole breed into the Deccani breed to create the 'NARI Suwarna' sheep in the mid-1990's at the NGO "Nimbkar Agricultural Research Institute" (Maharashtra, India) with funding from the Australian ACIAR to create a new breed with better reproductive and meat performances than the indigenous Deccani breed (Walkden-Brown et al., 2009). In challenging environments, the use of the Boorola gene is one of the very few examples where DNA technologies have been shown to clearly benefit BPs in the field.

The CBBPs have in general been more viable and sustainable for simultaneous conservation and genetic improvement of local/indigenous livestock under smallholders' farming systems (Philipsson et al., 2006; Wurzinger et al., 2011), because such decentralized nucleus schemes, handled by the farmers or their breeding organization, account for the farmers' preferences, decisions and participation from inception to implementation (Mueller et al., 2015). However, some centralized BPs operated by governmental institutions' farms and research stations or by private companies have shown potential contributions to the genetic improvement of indigenous breeds using closed or dispersed nucleus breeding herds/flocks and have demonstrated impacts for instance in Kenya for sheep and goats (cases 4 and 5) or in Brazil for cattle (case 13).

2.1. Evaluation of ruminant breeding programmes

2.1.1. Cattle and sheep breeding programmes in Latin America

Breeding and conservation programmes in Latin America generally combine public and private contributions. Commonly, the government supports the activity with funding for research, generally Dairy and Products Annua conducted by national institutes for agricultural research (such as EMBRAPA in Brazil and INIA in Uruguay) or universities, and sometimes takes the initiative to promote breeding activity and conservation programmes. Recording systems and herd books are generally administered by breeders´ organizations. National genetic enterprises or AI companies are practically absent, but local branches of the global players are active and import mostly semen, but also embryos or even live animals (e.g. CRV, Topigs, etc.).

Dairy Cattle in Brazil

In Brazil, 10% of the largest producers account for more than 60% of the country's production (USDA, Dairy and Products Annual, country Brazil). Accurate genetic evaluations of each battery of bulls have been annually published since the start of the two main Zebu (Gyr and Guzerá) dairy breeding programmes. The annual phenotypic increase for milk yield revealed favourable improvements about 40 to 100 kg/year depending on the population (see Annex 6). During the public presentation of the annual sire summaries, the technicians from the breeding associations and researchers from Embrapa Dairy Cattle and universities give presentations to facilitate knowledge transfer to farmers. According to the interview and literature (see Annex 6), the main improvement came from using proven bulls from dairy BPs developed in Zebu breeds and crossbred Bos taurus x Bos indicus, but only 10% of dairy farmers use insemination. So improved genetics do not contribute as much as expected to small and dairy producers. More generally the national huge increase in production came from an increase in number of cows and some improvement in herd sanitary-related actions (in some areas). Currently, there is no public policy to stimulate and change the situation to increase the impact of dairy BPs. Breed associations need more support from public policies and research institutions to move forward. Funding is missing to provide support and extension. It is difficult to convince the dairy industry, semen production centres and Ministry of Agriculture to have a programme devoted to genetic improvement for small and medium dairy producers.

Beef cattle and sheep in Uruguay

In Uruguay, each cattle or sheep breed has its own private breeding association, all of which are part of ARU as described for sheep breeds in Annex 8. The breeding goals are collectively defined in workshops involving breeders, commercial farms, industry representatives and research institutions. Bioeconomic models help to determine the economic values for the traits of interest and are used in the creation of selection indices. INIA carries out the genetic evaluations of sheep and beef cattle. While there is no official study on the national benefits of BPs, indices expressed in dollars help track genetic trends and monitor the success of the BP. There are dedicated websites for communication and exhibitions for sheep and cattle breeding. However, the level of dissemination of genetic gain to commercial breeders is not well assessed. Based on a survey, 40 to 45% of commercial breeders use estimated breeding values to buy rams or bulls, but the proportion is very variable across breeds and the preferred criteria are not known. The system lacks official tools to optimize matings at the population level, and breeders' decisions shape breeding outcomes. Accounting for inbreeding coefficients in their selection tools is under consideration. Breeding goals are re-evaluated every ten years. In the future, the focus will include adaptation and resilience objectives and collaboration with breeders to mitigate environmental impacts, using genomics and working on traits like faecal egg count, feed efficiency and methane emission (Blometto et al. 2023).

2.1.2. Cattle, buffaloes and small ruminants breeding programmes in India

Cattle and buffaloes

The Indian dairy production system is based on very small smallholders. 80% of these smallholders (=120 to 140 million families) own less than 1 hectare and have 2 to 5 cows with a low production (a few litters a day). Dairy production is usually not the only economic activity for a farmer but it has a strong cultural basis. The National Dairy Development Board (NDDB), created in 1965 to contribute to the growth of the Indian dairy sector, and the BAIF Development Research Foundation (an NGO created in 1967 by a disciple of Mahatma Gandhi) play a major role in the genetic improvement of dairy cattle and buffaloes in India (case 6, see Annex 3). Both organizations rely a lot on imports of semen or embryos from abroad to produce sires of sons (mainly Holstein or Jersey), the selection of crossbred (*Bos Taurus x Bos Indicus*) or pure *Bos Indicus* bull dams and artificial insemination on farm with semen of their sons.

BAIF is mainly disseminating semen of Holstein, Jersey and crossbred bulls of these breeds with indigenous *Bos Indicus* breeds through AI. A relatively large progeny testing program coordinated by NDDB and supported by the World Bank started at the beginning of the 2010's to record phenotypes under a digitalized system focussing mostly on the crossbred cattle population and, to some extent, on buffaloes. However, it concerns less than 0.1% of India's 150 million cows and 100 million buffaloes. The main goal was to select bull dams and implement a simple progeny testing evaluation of young bulls. The best bulls were producing semen for 10 years or more. Their semen was used in one region before being used in another one further away to avoid inbreeding. More recently, the development of genomic selection theory and tools led to the creation of two (currently separate) milk-recorded crossbred reference populations for genomic selection on milk yield: 1/ NDDB (with involvement of Danish scientists) and 2/ BAIF which benefited from the BMGF support and collaboration with scientists from Australian universities of New-England and of Queensland, and INRAE in France. BAIF has set up an accurate smartphone-based herd recording system for use by farmers and specialized technicians for milk recording (Al Kalaldeh et al., 2021). The availability of high-quality data has resulted in Genomic Estimated Breeding Values (GEBV) with moderate accuracy (~0.45) for some breed/crossbreed groupings of Indian dairy cattle (Al Kalaldeh et al., 2021). But the use of these GEBV is still very limited, in particular, because the Indian laws still require for Holstein or Jersey bull dams an unrealistically high minimum level of raw milk production. An additional challenge is that male calves that are not used for breeding cannot be slaughtered by law.

Small ruminants BPs in India

In India, small ruminants need special attention due to their socio-economic importance in rural and often highly disadvantaged communities. They are the second most important meat-producing species after poultry (Gowane et al., 2019). There are governmental incentives to develop BPs for small ruminants in low-input systems as well as NGO initiatives to develop CBBPs such as the one from Nimbkar Agricultural Research Institute (NARI) in Bihar state for goats (case 7, see Annex 4). There is not yet a formal evaluation of these breeding programmes, but emerging CBBPs in the last five years appear to be a better option than the 'All India' project which struggles to get sufficient financial and technical support to develop efficient indigenous goat BPs. Genetic improvement of small ruminants should be accompanied by attention to shrinking grazing resources, which would require strong political and financial support. A lack of linkage between the market and producers discourages farmers from adopting clear breeding objectives like improvement the growth rate, as animals are seldom sold on a weight basis. Apart from government agencies, involvement of the private sector, non-government organisations, local co-operatives, self-help groups and self-sustainable CBBPs can strengthen market linkages as demonstrated in the Bihar goat CBBP. Strengthening of the existing infrastructure along with technical input and skilled manpower are essential for achieving the breeding objectives.

2.1.3. Small ruminant breeding programmes in Africa

Ethiopian small ruminant CBBPs

The CBBP approach was introduced in Ethiopia in 2009 by the International Center for Agricultural Research in the Dry Areas (ICARDA) in academic partnership with the International Livestock Research Institute (ILRI), Austria's University of Natural Resources and Life Sciences (BOKU), and the Ethiopian National Agricultural Research System (case 3). The motivations were to improve sheep production and the livelihoods of farmers´ families. The implementation of CBBPs started at a pilot scale with 4 communities (Afar, Bonga, Horro, Menz), representing different sheep breeds and production systems. These pilot CBBPs have since expanded to include more than 13,000 households in 130 villages which derive direct benefits from the scheme and the emergence of a functional cooperative organization in each village (Haile et al., 2023).

Apart from the pastoral Afar CBBP, the 3 other pilot CBBPs obtained quantifiable genetic gains in their first ten years of development and impacted the livelihoods of rural communities (Haile et al., 2020). The main selection trait identified through participatory approaches was 6-month weight for sheep in all three sites. This weight increased over the years in all sites. In Horro and Bonga, where resources such as feed and water permitted larger litter sizes, twinning rate was also included in the breeding goal, and prolificacy significantly increased over the years. This increase in litter size, combined with the increased 6-month body weight, improved income by 20% since CBBP inception and home mutton consumption per family from one sheep per year to three. Most of the participating households in Menz CBBP have graduated from the government-run safety net programme that meets short-term food needs through emergency relief and now use income from the sale of sheep to meet their subsistence needs.

Sheep/goats in CBBPs have shown improved performances, such as lamb/kid growth rate, lambing/kidding interval, reduced mortality and attracted higher market prices compared to sheep/goats from non-CBBP farmers in all communities. In addition, CBBPs enable the conservation of indigenous animals through their use, their genetic improvement, and the reduction of mortality and inbred matings. “Best of stock” growing breeding lambs/kids, previously sold and slaughtered, are now retained as breeding stock in all communities. High demand for breeding males from neighbouring communities, from other government programmes and from NGOs in all sites, provides the foundation for specific business models around the production of breeding sires and semen for artificial insemination (Haile et al., 2023). Most of the established farmers’ cooperatives have managed to build capital (e.g., Boka-Shuta cooperative in Ethiopia has about USD 110,000) as there is enough market demand in Ethiopia, and also an export market that helps to make the CBBPs sustainable.

However, the CBBPs still receive technical and financial support from CGIAR-centers (Haile et al., 2023). A systematic and regular data recording has been implemented in all the 130 CBBPs. Different challenges came up with time and possible solutions were identified. The challenges were the low number of animals per household, the management of traits with low heritability, the difficulty observed in balancing breeding objectives and farmers’ qualitative preferences, the lack of willingness to participate (dropouts) among the members, the within members’ management problems regarding financial issues, disease outbreaks and feed shortages.

Kenyan sheep and goat BPs

Investigations on productivity improvement using indigenous breeds in low-input systems are scarce. However, some efforts have been undertaken during the last decade to investigate productivity improvements, for example for small ruminant BPs in Kenya. Oyieng et al. (2022) recently demonstrated that phenotypic and genetic trends were positive for weaning and mature weights in all breed groups (from pure Red Maasai to pure Dorper with intermediate crossbred groups) at the International Livestock Research Institute (ILRI) ranch (case 4, Annex 2). Sila et al. (2021) evaluated the performance of ILRI improved indigenous sheep and goat breeds and their contribution to household revenues, five years after their initial introduction into low-input smallholder farming systems in two communities of the Nyando basin of Lake Victoria, covering 169 farms from Kericho and Kisumu counties of western Kenya. The growth rate of the improved Red Maasai and Red Maasai x Dorper crosses was not different from that reported for these animals under the semi-arid environment of the ILRI ranch (Zonabend König et al., 2017). The improved indigenous breeds that were introduced into the smallholder farming systems and their crosses with local animals exhibited higher growth rates (e.g. +47.5% from birth to one year old for Red Maasai compared to the indigenous sheep breed in Kericho county), resulting in increased net returns from rearing sheep and goats. The farmers earned higher returns from goats than from sheep in the two counties.

The dairy goat CBBP in Kenya (case 5) is the story of how a successful BP can become a failure due to a lack of long-term strategic planning. The project was implemented by the NGO FARM-Africa in collaboration with ILRI to address the poor milk production and growth rate of the East African indigenous goats, by crossing them with imported Toggenburg dairy goats as described in Mueller et al. (2015). FARM-Africa managed and facilitated the operations of the project from its inception in 1995 until 2004, then it handed over key responsibilities to the communities through a new umbrella organization, created as part of the project, the Meru Goat Breeders Association. The pure Toggenburg goat population grew from the initial 130 animals to more than 1000 in a period of 10 years. The immediate positive impacts of the project were both at individual and group levels: individual farmers were able to own the goats to obtain more milk for home consumption, and to earn from sales of both milk and animals. Milk production increased from approximately 0.25 l by indigenous goats to 1.0 l by crossbreds and 2.0 l by 75% by exotic goats.

The popularity of the crossbreds from the project led to a high demand for breeding animals, pushing up the price of breeding animals. Kenyan dairy goat farmers were victims of their own initial success, as prices for improved animals became so high that the farmers sold off the genetic improvement that they had achieved (Ojango et al., 2010). In particular, the Rwanda government, after the war, was very interested in buying Kenyan dairy bucks to reintroduce good livestock in the country, and bought all top young bucks from Kenyan farmers, who thought that it would be easy to start again their CBBP applying the same principles. But they failed to reach the same highly improved breed and lost the market. The biggest problem in replacing and multiplying the stock was the small scale of the introduction of the improved animals in the community.

2.2. Evaluation of monogastric breeding programmes

2.2.1. Poultry BPs in Africa

Raising poultry is an important source of income for poor, rural communities in many low-income countries. Chickens have a high reproduction rate per unit of time compared to other domestic livestock. For their production, they require very low capital investment, inputs and space. Consequently, they are an integral component of the livelihoods of most rural, peri-urban, and urban households in most parts of low-income countries (Dolberg, 2023).

Due to the low performances of indigenous chickens, attempts have been made since the 1950s to introduce different commercial chicken lines and breeds (White and brown Leghorns, Rhode Island Red, New Hampshire, Cornish, …) to smallholder farms to improve chicken production (Mesele, 2023). In addition, crossbreeding unselected indigenous chicken with those commercial lines has been used to produce crossbred chicken with different degrees of exotic breeds in all low-income countries. While a lot of failures of these attempts were observed until the 2000s, the development of new promising strategies emerged within the last decade that combine the use of improved hens (from relevant exotic lines) crossbred with indigenous cocks. Although a few intensive production systems exist in rural Africa, the local village chicken system (local indigenous breed reared on a scavenging feeding system) still dominates rural production today. It is a common belief that village chickens are the key to increasing food production and income and to providing increased opportunities for women in many villages across rural Africa. These village systems have the potential to move from a subsistence-type setting to a semi-commercial production system if management, marketing, and disease issues can be overcome. This would provide greater opportunities to increase food security and household income across much of rural Africa, especially among disadvantaged members of villages. To do so, providing access to improved chicken breeds is one of the key elements to increase the rural poultry productivity at the small-scale farmer level. The ‘African Poultry Multiplication Initiative’ (APMI) from the World Poultry Foundation (WPF) aimed at securing the chain from hatchery to brooder units to smallholder farmers. This initiative depends on the availability of improved parent stock genetics suitable for African production conditions.

Poultry production in Ethiopia

In the 1970s and 1980s the Ministry of Agriculture in Ethiopia initiated a cockerel distribution and exchange scheme. This involved the importation and distribution of exotic cockerels to be used as breeding males in villages. The scheme failed because of the lack of an appropriate design of crossbreeding scheme, the mis-adaptation of the exotic cocks and the farmers’ willingness to keep their local cocks. Today, Ethiopia appears to make coexisting local indigenous breeds without any structured BPs with imported commercial dual-purpose breeds that are better adapted to sub-Saharan environments than earlier attempts in the 1970-1980s (Tilahun et al., 2022).

Since 2010, a private company, Ethiochicken, has emerged as a major distributor of 1 day-old chicken in Ethiopia (case 2). It served about 46 million 1-day-old chickens to about 8 million smallholder farmers in Ethiopia on a yearly basis. Ethiochicken is responsible for over 20% increase in eggs consumed in Ethiopia. It owns very well-equipped parental stock farms and hatcheries in Ethiopia. Most of the day-old chicks go to mother units whose staff is trained and received the technical support from Ethiochicken agents (for instance if mortality is too high, they get advice for management improvement). At 5-weeks of age, the chicks are sold at a fixed price decided by Ethiochicken (depending on the market demand and offer) to smallholder farmers. They are encouraged to keep the females on the farm for egg production.

Today, Ethiochicken is the main African customer of SASSO-Hendrix Genetics dual-purpose breeds whose BPs are run in Southwest of France. SASSO´s market share is increasing in sub-Saharan Africa in the dual-purpose segment. A major impact of Hendrix Genetics in Africa comes from the ‘Hatch Africa’ group based on the dissemination of SASSO dual-purpose breeds across six countries in sub-Saharan Africa: Ethiopia, Uganda, Rwanda & Kenya, and more recently, Ghana and Côte d'Ivoire. High biosecurity levels are required, purebred lines are kept in France, and their matings to produce the parent stocks are carried out outside Africa (in France, Brazil and Canada). This organization secures poultry breeding stock for use in Africa but leads to major logistical challenges (administrative papers, vaccine, flight schedule and delays…) and a high level of dependence on the supply of improved lines.

Poultry production in Burkina Faso

The two BPs in which the breeding company SASSO-Hendrix Genetics is involved in Burkina Faso (case 1, Annex 1) seem successful thanks to the strong relationships between SASSO-Hendrix team and Burkina Faso’s local farm managers and staff. They are conducted by a well-trained local team in Boussé, a small town located 60 km northwest of Ouagadougou, that records properly data and pedigree and is technically supported by SASSO-Hendrix Genetics R&D teams on a long-term perspective. There is important genetic gain in body weight for the SASSO dual-purpose breed measured in local Burkinabe conditions (Duijvesteijn et al., 2022). High biosecurity levels being required, purebred lines and mating to produce the parental stock are carried out outside Africa. This organization secures poultry breeding stock for use in Africa but leads to major logistical challenges and a high level of dependence on the supply of improved lines.

As regards to the local BP of ‘Coq du Faso’, the breeding goals are well-defined, data and pedigree collection are correct, and a ‘state-of-the-art’ genetic evaluation is carried by a volunteer geneticist. The local BP of ‘Coq du Faso’ is self-sufficient, but the sales of chicks are just enough to let the farmers’ cooperative go on without subsidies. The local BP is interesting because it helps improve a local chicken breed and fits better with the preferences of smallholder farmers and consumers than the use of commercial exotic chicks. But it is a ‘niche’ market. In 2020, it was considered that this local BP helped approximately 1,000 smallholder farmers to increase their productivity 100-fold (https://www.poultryworld.net/poultry/crossbreed-chicken-increases-production-100-fold/). The local programme seems sustainable as long as there are no political issues in the country rendering for instance access to feed difficult or too costly, and that SASSO-Hendrix Genetics stays a technical helper and maintains its recurrent test in Boussé. The SASSO BP, based on slow-growing lines with low levels of inbreeding, appears to be more efficient and economically sustainable to feed the 8 million people suffering from food insecurity in Burkina Faso. SASSO sold close to 30,000 parental stocks in Burkina Faso. The recurrent test of SASSO dual-purpose lines in Burkina Faso is expected to be maintained as it is important for SASSO to increase its market shares in tropical countries. But the success of the organization is sensitive to all the risks (e.g. cost of feed, political instability, availability of qualified personnel) which would lead to the bankruptcy of the local cooperative.

2.2.2. A local chicken breeding programme in Thailand

Thailand is a major producer and exporter of poultry meat, but most chickens originate from parental and grandparental stocks imported from the United States of America and the United Kingdom. As a response to the issues of food security for Thai smallholder farmers and loss of native genetic resources, Suranaree University of Technology (SUT), the Department of Livestock Development, and Thailand Research Fund collaborate on an academic BP development in order to create the Korat chicken (case 9, Annex 5). The slow-growing Korat chicken is a crossbreed between a male of the native Thai Leung Hang Khao line and a female of the SUT line in Thailand, which is characterized by superior meat quality with low fat, rich collagen, and good texture (Katemala et al., 2021) that can penetrate to high-end market both in food services and shopping canters. Chicken are sent to the market at 1.2–1.5 kg bodyweight at about 10 weeks of age. Rearing of this breed is encouraged by the agriculture sector of Thailand which advocates the smallholder farmers to rear indigenous chickens to develop the rural economy.

The BP is conducted by trained staff in SUT in well-equipped buildings for the parental stocks and production farm. The BP budget is funded by funding agencies and by the SUT farm, a social enterprise that supports students and trains smallholder farmers. The government pays the permanent academic staff from the university and partly from the SUT farm. Students use the farm for practical learning and can, after graduation, create their own farm with Korat chicken. There is also an online non-degree course open to anyone on how to manage Korat chicken, including nutrition, nursing, food technology, how to use information technology to improve the efficiency of production, and market studies. In the SUT farm, 50,000 chicks are produced each month and sold at 1 day old to about 400 smallholder farmers (rearing 100 to 1,000 chicks while the medium-scale farmers in North-East of Thailand have up to 10,000 chicks). Currently, there is no delivery service, farmers have to come and buy the chicks at SUT. Currently, there are not enough funds and extension staff to extend the programme. The Korat chicken is a ‘niche’ market, impaired by higher prices than regular chicken. In addition, volatile weather conditions, which contribute to the outbreak of diseases, are another threat to this poultry production system in open houses.

2.2.3. A pig breeding programme in Haiti

The Haitian pig breeding plan arose from the need identified by the government, NGOs and farmers’ associations for a rustic pig adapted to low-input areas after the local breed disappeared at the end of the 70’s due to an African swine fever outbreak (case 14, Annex 7). Started in the 1980s with a few imported black pigs from rustic breeds in collaboration with French partners, the BP relied on a primary selection centre and multiplication centres that would disseminate the genetic gain achieved in the primary centre by selling crossbred sows and piglets. In 1996, 43% of the multiplication was achieved in the principal centre, and 57% from secondary centres. The initial objective for the maternal line was to have 10 piglets weaned per litter in the maternal line (Chinese x Gascon breeds) and 7 piglets per litter in the paternal Créole line. A study in 1989 (unpublished) reported results of 7.78 piglets for the Créole breed, 10.01 and 10.63 for the two Chinese crosses in the primary selection centre, so the objective was reached. However, in a small study at the farm level, performances were reported to be much lower in the farms than in the primary selection centre (piglets weighed 2.8kg at 35 days in farms vs 7.5 kg in the primary selection centre and weighted 6.5 kg vs 20kg at 75 days). Performances in the secondary multiplication centres were also highly variable. Feed was the main limitation to sustaining these centres with good economic return: local feed was poor, so good quality feed was mainly imported, and production costs were more than twice pig prices. However, with the fixed prices sustained by the programme, small farmers did buy the piglets from the programme, that were heavier and in better shape than pigs born on their farms. Altogether, the program lacked sustainable feed supply and communication means, and local infrastructures to sustain the building of proper sanitary surveillance, regulation, and training network, resulting in frequent sanitary hazards. Besides, difficulties were reported in motivating farmers to group and stakeholders to gather and get organized to put together all the necessary elements of the production system. Finally, securing constant funding and political support was difficult and affected priorities.

Despite these difficulties, about 13,000 pigs were sold from the multiplication centres between mid-95 and mid-98, including 50% sows: among these, 75% had at least one litter, with 1.22 litter per year, and 5.43 piglets per litter (much less than the 10 piglets reached in the selection centre). These led to about 32,400 piglets produced over 3 years, resulting in a contribution of 15,000 pigs per year to the farmer level. This is relatively low in regard to 700,000 pigs on the island. However, it maintained the sustainable use of black pigs adapted to the local production, increasing the livelihoods of smallholder farmers (piggy bank effect). A number of crosses with white pigs could be found in the country, making it more difficult to fully assess the impact of the BP.

D. Recommendations for an improved evaluation of the impacts of the breeding programmes

For the last 5 years, efforts have been made, mainly by researchers, to implement and document formal socio-economic evaluations of BPs in challenging environments. Such efforts may provide governments and NGOs with the information necessary for creating sustainable CBBPs at larger scales (see part E).

As analysed by Mueller et al. (2015), the key factors affecting the sustainability of a CBBP are the recognition of an a priori interest of farmers, the involvement of local institutions/organizations and a low/moderate dependence on external support. In fact, it has to be noted that most of the key factors affecting CBBPs are also relevant to other types of BP.

Breeding activities necessitate substantial investments for the various stakeholders. As the added economic and social values generated by the BP at the country/territory level are difficult to assess, there is a strong issue with getting a fair distribution of the added values among the stakeholders, in particular for smallholder farmers. Experiences collected in our case studies (see section B.2) demonstrate that BPs, in particular for smallholder systems, will always need external inputs (technical support and/or financial funds) to be sustainable. This also holds, in high-income countries, for numerous BPs that benefit from partial public funds. Continued support will depend on positive evaluations of the BPs. Ideally, all criteria defined in section B.1 should be analysed in economic terms, i.e., on the basis of cost-benefit analyses. However, this may not always be possible because of the nature of the inputs and outputs involved, the difficulty of collecting the relevant information or a lack of expertise to perform the analyses. In addition, our analysis reveals that only a very limited set of the formal criteria defined in section B.1 are properly documented, even in the more advanced and successful BPs. Therefore, BPs need to be evaluated not only in terms of formal indicators but need also to include criteria that allow the consideration of less tangible inputs and outcomes (e.g. volunteer scientific support, impacts on malnutrition, gender roles or environmental impacts).

Last but not least, periodic evaluation of ongoing BPs should still be set up for the identification of drawbacks, including the perceptions of farmers in the evaluation process. Some first attempts have been reported (see, for instance, Annex 2 for Kenyan sheep BP). They were not conceived to be used on a regular basis. The importance of flexibility and continued revision of structures and organization of the BP is essential as local institutions/organizations may lack stability, change their intervention policies or become inadequate as the BP grows in number of participants.

1. Organisational, technical and financial support from governmental agencies or NGO

The analysis of case studies highlights the importance of the involvement of local institutions in the planning and implementation stages and also reveals a clear dependence of most BPs on organizational, technical and financial support. In particular, completely self-sustained CBBPs seem to be difficult to design as CBBPs aim at the collaborative action of many smallholder farmers, with the support of local research and extension groups. The main components are the involvement of NGOs that support very poor men or women, the provision by NGOs of micro-credit and training to help these groups establish CBBPs. In all case studies, training of both smallholder farmers and extension staff appears to be essential regarding breeding and overall management practices (reproduction, health, nutrition, breed choice according to the input level of farm systems, …) as well as in their ability to market the products at fair prices. Reducing animal losses through better management helps to increase the amount of product available for marketing and decrease the issue of low production of local animals.

In low-income countries, sustainability is uncertain in BPs dependent on external funds or external technical support or requiring expensive technical services (like genotyping platforms and genomic evaluations). The difficulties faced by development agencies in intervening with conventional technologies in low-input animal production systems and remote areas also apply to genetic improvement technologies. Performance and pedigree recording requires support from technically skilled staff, and controlled mating entails extra labour or additional infrastructure. However, there are situations (e.g., in India), where, for example, artificial insemination is relatively easy to implement in dense areas when liquid nitrogen is affordable and transportable on motorbikes to smallholder farms (case 6, see Annex 3).

Breeding strategies can, therefore, only be successful in the long term if cooperation between the various stakeholders works well and funding is secured. All stakeholders must actively participate, and science must lead in filling knowledge gaps. Guidelines based on scientific findings are the precondition for developing a sound legal framework. In addition, politicians, farmers and other stakeholders need to be made more aware that different breeds have different environmental and management requirements. High-performing, exotic breeds usually require better management and are more sensible to challenging environments like heat stress, water stress, poor feed and fodder quality, or disease pressure. Government authorities could regulate whether and which imported breeds are used based on agro-ecological zones, existing infrastructure and other socio-economic data for different livestock species. For example, only exotic cattle or goat breeds proven to have no problems with altitude sickness could be used at high altitudes. This can be extended to any feature depending on local conditions (e.g. extreme weather conditions, low quality of feed and forage, limited access to water).

2. Infrastructure and technical considerations

Stakeholders involved in implementing BPs need to pay attention to infrastructural and socio-economic issues. Mueller et al. (2015) mentioned that CBBPs are more frequent with keepers of small ruminants in low-input extensive systems, in particular smallholders of local breeds, than with cattle, pigs or chickens with which farmers may have easier access to BPs from global breeding companies, in particular through AI use. Furthermore, CBBPs or national BPs for dairy cattle or chicken will hardly be competitive, given the monopolization of the breeding sectors for these species. Cattle or chicken CBBPs may, however, be valuable options for keepers of indigenous breeds where there is no offer of external breeding stocks. In addition, a significant proportion of exotic genetic material is often used for crossbreeding with native ones in order to combine the positive characteristics of both breeds (higher output, better adaptability to local environments). Systems with crossbreeding of native and exotic breeds are rare in CBBPs, due to increased infrastructural demands of systematic crossbreeding. Such a system has, however, been successfully developed for the 'Poulet du Faso' broiler crossbred BP (case 1) thanks to the strong partnership of the local selection centre with a global breeding company. Yet, genetic improvement can be easily achieved with composites in regions where governmental or NGO-led distribution of crossbred animals with high levels of exotic blood, as is the case in Kenyan sheep and goats BPs (cases 4 and 5) and Indian cattle (case 6).

3. Data recording plans and genetic evaluation tools

Data collection, data analysis and feedback to farmers are also key elements in the context of BPs. Farmers need to have some measurable benefit for their efforts to collect data. Without feedback, the viability of the recording plan proposed by a breeding organization is questionable.

The aim should be to identify simple, cost-effective and time-saving recording systems that can be maintained by breeders' organizations. Some programmes, like those funded by the BMGF, for smallholder dairy farmers in India and countries like Kenya, Ethiopia or Tanzania in sub-Saharan Africa use information and communication technologies (ICT) to digitally capture and submit data that are sufficiently large for use in genetic evaluation (Marshall et al., 2019; Heather et al., 2021). However, under smallholder farmer conditions, a very accurate and detailed recording might not be feasible unless these activities are linked to market incentives (see Annex 2).

As a starting point, performance data without calculating EBVs can be used for making selection, decisions. This might lead to less accurate selection decisions, but it helps farmers to familiarize themselves with how to interpret records. Genetic evaluation can be introduced in the next step. It is essential that farmers receive sufficient training to interpret estimated breeding values and to choose their breeding stock based on selection indices in accordance with their breeding goals.

4. Impact of BPs on livelihoods

Assessing the impact of breeding programmes on farmers' livelihoods is very complex and difficult, as conditions often change due to other interventions. Nevertheless, surveys can help gain insights into these changes. For this purpose, it is important to collect baseline data at the beginning of a BP that can serve as a comparison. Additional income from selling more and/or better-quality products and the sale of breeding animals is a possible indicator. For example, better systematic registration of date of birth, of heats, of insemination, of calving/lambing, of mastitis events can considerably improve the management and the productivity of cattle or goat. The effects often only become visible and measurable after a longer period of time. This is another difficulty in the BP evaluation. The analysis should not only cover the individual farm but also the entire value chain. This makes it possible to show that the regional or national economy benefits from improved production. The Ethiopian Menz sheep CBBP demonstrated that home consumption of mutton increased, and families could leave the government-run safety net programme.

However, it should also be borne in mind that these short-term economic improvements can sometimes have negative environmental impacts (e.g. more intensive use of water resources linked to the expansion of livestock populations).

5. Impact of BPs on the environment

(i) While indications exist either in terms of new traits to be included in the breeding goals (case 17, Annex 8) or more frequently on conservation of biodiversity (e.g., use of local livestock breeds and inbreeding avoidance), evaluation of environmental impacts is quite scarce in the literature for low-input systems in low-income countries. Various methods exist to determine the carbon, ecological or water footprints of livestock production activities. However, these methods usually require expertise and very detailed data on the different production levels, which are often not collected under smallholder conditions. As suggested by Lamuno et al. (2018), during field visits, the evaluator may notice and discuss potential areas of concern with the farmers. The evaluator may ask questions about sources of feeds and their availability, water use and waste management. However, it is even more difficult to assess all these impacts at the animal level than at the herd/flock level. This may limit the assessment to breeds/lines comparisons regarding feed efficiency and productivity.

(ii) For ruminant systems, a special attention can be dedicated to on-site inspection of pastures. Their composition, management (e.g., rotational grazing, stocking density), changes in vegetation cover, soil conditions, damage to vegetation and evidence of practical mitigation actions to improve natural resources offer insights to find out if there is a risk of resource overuse. The most acute problem is methane emission from ruminants. There is a large number of low-productivity cows in many low-income countries, *significantly contributing to a huge production of greenhouse gas*, which should be a fundamental incentive to increase productivity through genetic improvement of livestock.

FAO (2023) indicated that, in South-eastern Asia, total emissions per kilogram of eggs in an extensive system are much lower than in an industrial/intensive system. Emissions related to manure, however, are significantly higher due to the slow-growing poultry breeds and feed used (mostly crop residues and food waste in extensive systems). Extensive or backyard systems are characterized by animals freely living with simple housing and a low fraction of commercial feed from local sources, and products sold on local markets. In addition, no gas emissions occur from energy use in either on- or post-farm operations. Industrial/intensive systems, in contrast, generate energy-related GHG emissions from packing and processing activities. Furthermore, these systems often rely on imported feed grown in areas which emit GHGs from land-use conversion processes (for example, deforestation to grow soybeans). Therefore, the scavenging poultry systems deserve interest in terms of environmental effects. However, the very low feed efficiency of local chicken breeds may completely counterbalance these advantages when considering a fixed amount of broiler or egg production.

E- Scaling up breeding programmes in challenging environments

A country with national breeding programmes for its animal resources strengthens its food security and provides job opportunities. These are the reasons why animal breeding has been traditionally supported by the states and large national BPs have been implemented for most livestock species in high-income countries during the 20th century. The development and scaling up of these BPs were made possible due to continuous commitment and policy support from the governments as well as private sector investments including farmers, breeders' associations and private companies. Currently, these BPs are mainly run and financed by farmer cooperatives and breed associations in ruminants and by private breeding companies in monogastric species. Nevertheless, there are always some significant public funds to at least support R&D genetic innovations, such as the implementation of genomic selection during the last 15 years for the main breeds and commercial lines across the world.

In low-income countries, the appropriate infrastructure, well-trained and skilled staff, legal framework, and the public funding to implement such BPs are largely unavailable. Therefore, past attempts to replicate successful approaches from high-income countries often mismatched with local characteristics of low-input systems and lack of IT infrastructure and, as a result, most of them were not very successful.

To be able to deliver any impact, the scope of a BP must be consistent with the stage of development of the area and the resources available. In parallel of implementing the BP, continuous improvement and changes in farm/herd management are needed. Taking a sectorial approach, all stakeholders along the different value chains must constantly improve their services to meet future demands on animal products. There are important needs in developing local infrastructures and proper sanitary surveillance, regulation, and training for vet control as sanitary hazards are high and outbreaks of infectious diseases are expected to become more frequent due to climate change. Therefore, BPs in challenging environments will always require some public support as new challenges emerge.

1. Breeding strategies to increase the impact in challenging environments

Long-term and simple strategies are necessary as the BP must not depend on prerequisites that cannot be guaranteed, such as intensive feeding systems and state-of-the-art health management needed for high-producing breeds or lines used in temperate and high-income countries. Genetic improvement may concern local breed improvement through pure breeding and the introduction of exotic breeds for crossbreeding or breed replacement. In most of the reported success stories for livestock genetic improvement in low-input systems, there has been a certain degree of crossbreeding between exotic and local breeds, with scientific recommendations given to generate animals with about 50% of the genes from temperate breeds (Philipsson, 2006; Galukande et al., 2013), or even up to 75% when the local conditions are favourable (availability of good feedstuff, moderate pressure of pathogens…). In any case, improved germplasm, whether in the form of live animals, semen, embryos or eggs, has to be produced and disseminated efficiently to enable the BP to be successful. This point is an important limitation to the development of an efficient livestock sector as we observed in diverse case studies lack of information and absence of large dissemination programmes of genetic improvement even when an efficient BP has been developed. Another point is to construct the business model that allow dissemination to contribute effectively to the economic balance of the BP.

Although crossbreeding between local and exotic breeds can be useful and successful in some areas, there is a risk that native breeds will be replaced by exotic ones or disappear completely through indiscriminate crossbreeding due to limited means and infrastructure. These breeds would then not be available to more extreme conditions and remote areas, where they have a competitive advantage due to their better adaptability. Terminal crossbreeding, where all crossbred progeny is slaughtered, might be a relevant strategy (Leroy et al., 2016), at least for species with high prolificacy as demonstrated in our case studies for poultry BPs. Even when some sort of crossbreeding is opted for, a parallel BP for the local parental breed must be maintained. Preserving the genetic resources of local and native breeds is therefore a major challenge to be considered in conservation programmes by all countries.

CBBPs typically target low-input systems and farmers within limited geographical boundaries having a common interest in working together to preserve and improve their indigenous genetic resources. CBBPs have been promoted as a way to fit the two goals, conservation and improvement of indigenous breeds, in a single programme. Nevertheless, it should be recommended to clearly distinguish between conservation programmes of endangered breeds and breeding programmes to ensure improved livestock and livelihoods of smallholder farmers in low-input systems. When livestock populations are not large enough, even success stories such as the Kenyan BP for dairy goat (case 5) may fail due to rapidly changing market demands resulting in a lack of a sufficient number of improved animals to simultaneously continue the BP and sell elite animals to other communities. However, the two goals - ‘conservation’ and ‘selective breeding’ - have been successfully associated in some programmes, such as in the case of the Black Bengal goat in India (see Annex 4). It should be noted that this breed is very common in West Bengal and Bangladesh and that successes in achieving both objectives are less demonstrated for endangered breeds. In some cases, national efforts are made to preserve rare breeds such as in India to maintain buffalo or cattle breeds able to survive in harsh environments (saline areas, forests, or Himalayan hills) or in Peru to conserve different coloured alpacas as farmers are opting for white animals due to market demand.

CBBPs were demonstrated as an effective and beneficial strategy to achieve genetic gain and to improve farmers´ livelihoods (Haile et al., 2020). At a small scale, the “community-based breeding” approach is inherently sustainable as it engages the communities, hence supports local-level decision-making, focuses on adapted local breeds, considers the constraints that smallholder farmers face and empowers farmers’ organizations (e.g., cooperatives) in low input systems. Pooling animals from different smallholder farms within the same village/community in a single breeding unit has been demonstrated as an efficient way to manage BPs for small ruminants in various countries. However, new paradigms are needed for i) dispersed CBBPs based on the needs and involvement of livestock keepers, and basic but systematic recording to overcome the problems of small herd sizes in genetic evaluation of future breeding animals; and ii) dissemination of the genetic improvement to livestock keepers in remote areas. Otherwise, livestock keepers will not benefit from any genetic improvement.

2. Ways for scaling up/out a breeding programme

It is possible to expand the size of an initial pilot BP, i.e., to scale it up vertically, or to replicate it in other geographical areas. This alternative way to increase the impact of a technical solution through horizontal scaling up has been called ‘scaling out’ (Kaumbata et al., 2020).

Support suggestions for out- and up-scaling CBBPs have been proposed by Mueller et al. (2019). The authors suggested three strategies to genetically improve a large proportion of a small ruminant population, e.g., sheep: 1) to substantially increase the number of male lambs sold for breeding per CBBP (up-scaling), 2) to increase the intensity of use of selected rams by means of artificial insemination (AI) or, 3) to further replicate CBBPs (out-scaling). These authors concluded that up-scaling the number of improved males from current CBBPs for dissemination and out-scaling current CBBPs are highly feasible strategies for population-wide genetic improvement. The more intense use of rams using AI was not cost-effective and was only justified in specific circumstances such as the use of sires with exceptionally high estimated breeding values as foundation sires for new CBBPs.

The experience in established sheep CBBPs demonstrates that selected surplus males become of increasing interest by neighbouring farmers and communities to be used for natural breeding. In sub-Saharan Africa, an out-scaling strategy for small ruminants CBBPs has therefore been developed (Haile et al., 2023) by multiplying small-scale CBBPs in various areas and countries, rather than implementing an up-scaling strategy to produce more stock or use more intensively reproductive technologies (such as AI, surrogate…). The approach, first initiated in Ethiopia in 2009, has now been introduced in other countries such as Burkina Faso, Iran, Liberia, South Africa, Sudan, and Uganda. Based on experiences in Ethiopia (see section B.2), the scaling out strategy, i.e., the implementation of additional CBBPs for small ruminants in other areas and other countries, is possible with appropriate private and public support for the revolving expenses, training, recording, breeding value estimation and other knowledge transfer associated costs (Haile et al., 2023). Each CBBP organized itself as a cooperative, designated enumerators and made them responsible for data collection.

However, a different challenge is the efficient dissemination of animals with improved genetic background produced in current CBBPs to create population-wide economic impact, i.e., the scaling up as defined by the World Health Organization (WHO, 2010) as “efforts to increase the impact of a technical solution successfully tested in pilot or experimental projects to benefit more people and to foster policy and programme development on a long-term basis”. Going from a BP developed at the community level to a regional or a national scale is not so easy to achieve.

To meet this challenge, Mueller et al. (2023) proposed a framework to develop, on a large scale, a commercially oriented organization of genetic improvement supporting a meat commercialization model based on the integration of CBBP cooperatives, client communities and complementary services such as fattening enterprises. They applied it to the Ethiopian Washera sheep breed based on simulation and extrapolation to 180 CBBPs of the genetic improvements that can be achieved in the currently established 28 Washera CBBPs in Ethiopia. As these 28 CBBPs can provide genetically improved rams to 22% of the four million heads, 152 additional CBBPs were needed to reach the whole population. It was shown that the benefits after 10 years of selection could be increased if the CBBPs are linked to client communities by providing them with improved rams.

Mueller et al. (2023), therefore, proposed an organization resembling the pyramidal structure existing in high-income countries with two tiers: CBBP communities and producer client communities. They demonstrated that Washera CBBPs cooperatives can benefit from a higher level of pyramidal organization to produce population-wide genetic improvement and economic benefits: " A new meat supply chain structure will benefit from the support provided by CBBPs role of genetic improvement providers, i.e., breeding cooperatives, supplying improved sires to client communities which benefit from the higher productivity of their animals and can concentrate on efficient meat production within their smallholder systems".

In the case of large ruminants, the herd sizes are most often limited to a few animals with high economic value. Whether the animals are raised to produce milk or meat, their age at first calving and/or their growth rate require a long unproductive delay before contributing to any economic return. In such a case, raising, borrowing or buying a bull to get calves is expensive and above all, risky. The best alternative is certainly the use of AI: it is safe, relatively cheap and also a way to access semen from superior males which may improve the future generation of calves. The examples from East Africa and India show the possibility to relatively quickly increase the average production of milk (or meat). However, it implies a serious training of the AI technician and the farmer, and before this, an important infrastructure to buy or collect semen from bulls raised under very strict hygiene, to keep this semen at extremely cold temperatures, to transport this semen to the farm at the correct time. These conditions may look impossible, but the large-scale examples of India or East Africa demonstrate their feasibility.

For the poultry sector in tropical conditions, some non-profit organizations such as the World Poultry Foundation (WPF, https://worldpoultryfoundation.org/global-initiatives/) or the Tropical Poultry Genetic Solutions (TPGS, https://worldpoultryfoundation.org/global-initiatives/) propose ways to identify private sector partners capable to scale the production and delivery of inputs and support services to smallholder producers. They seek partners that have an established business model which focuses on the delivery of inputs and services to rural households and are willing to invest time and resources into the rural poultry sector. The partners must have the capabilities to scale to the targets needed for the initiative to become sustainable, and to provide input supplies and support to farmers through extension and technical support in remote rural areas. They work to (a) establish a supply of improved genetics of low-input, dual-purpose chicken breeds; (b) scale day-old chick production systems to serve rural communities; (c) establish brooding units to properly rear, feed and vaccinate day-old chicks; (d) assist the companies in the recruitment and training of technical specialists to support the breeding units; and, (e) enable women smallholder producers who purchase chicks from the breeding units to raise them for meat and eggs for household consumption and sale.

3. Basic requirements for the scaling up/out to be a success story

In parallel of scaling up BPs, continuous improvement and changes in farm/herd management as well as availability of complementary and affordable services are needed, in particular to access to adequate and quality feed resources as well as to prevent and control diseases. Successful BPs require the interplay of all stakeholders along the value chain. So-called multi-stakeholder platforms can be crucial for BPs' success because they bring together diverse expertise, resources, and perspectives, which are essential for addressing complex challenges. These platforms facilitate collaboration among farmers, researchers, policymakers, private sector players, and civil society organisations. By fostering dialogue and coordinated action, multi-stakeholder platforms help align breeding objectives with local needs, enhance innovative practices, and ultimately lead to more resilient and productive livestock systems.

3.1. Permanent motivation and collective organization of the breeders

By using a participatory and bottom-up approach, CBBPs consider farmers' needs, attitudes, norms and beliefs (Zoma-Traoré et al., 2021a, 2021b). It ensures active participation of livestock keepers in the decision-making process, from inception through to implementation. The success of the CBBPs is based upon proper consideration of the farmers' breeding objectives, infrastructure, participation, ownership and market development (Wurzinger et al., 2011; Mueller et al., 2015; Haile et al., 2020). To scale the initiatives, the primary challenges are to keep the willingness to participate among an increasing number of members, to avoid dropouts, to balance breeding objectives and farmers' qualitative preferences, and to follow the way the financial issues are managed by the communities.

Maintaining the motivations of farmers can be difficult when breeding objectives are not fully shared by the community members or when visible results cannot be expected on a short-time scale. This could be the case for traits with low heritability such as fertility and survival. Participatory defined breeding objectives can become impossible to manage if too numerous. It is important to consider traits important to farmers, but time and effort should be sufficiently invested to come up with a manageable number of well-defined and heritable traits to use them efficiently in selection indexes. This requires in-depth discussions with farmers about expected selection responses of different selection index options, ensuring satisfaction with the set of traits to be included in the BP. This process should be regularly repeated over time with the increasing complexity of the BP due to the integration of new traits in the breeding goals and new stakeholders in the BP.

A strong limitation to up-scaling CBBP is that only a restricted number of farmers usually participate in a given research or development project. The possibility of involving more farmers may not be achieved with the scarce resources and the lifespan of a project. This expansion is more feasible with long-term support and commitments from local or national authorities. To multiply the number of CBBPs joining their efforts to increase the supply of animal products and improved breeding stocks, it can be more effective to target market-oriented farmers rather than the ones entirely subsistence-based. These farmers are more likely to respond to productivity improvements, particularly if low-cost options are proposed. In an out-scaling mode supported by development and governments, many aspects concerning the enabling environment for the realization of the technology proposed, such as infrastructure, extension personnel and research budgets for long-term projections, could be more easily gathered than for the small scope of a project affecting only a limited number of farmers. Successful out-scaling of community-based activities to a regional or even national level still has to be proven to work and will require adjustments to be made in the research project so that this becomes attractive, convincing and attached to local or national development goals. For growing impacts, the initiatives will need clear action guidelines with evaluation and management protocols.

3.2. Institutional supports and efficient agricultural policies on a long-term perspective

The gap between the farmer's perception and researcher's/government's interest is one of the major locks for the successful implementation of BPs. The implementation in a top-down manner mostly collapses once the withdrawal of financial and technological support or changes in government priorities (Nimbkar et al., 2008; Kristjanson et al., 2009).

Scientists have to provide evidence-based solutions to inform policymakers and engage them in a convincing discussion concerning the advantages of livestock improvement plans, their long-term nature, as well as their role in the rational management of the genetic resources, so that adequate policies are promoted to ensure long-term sustainability of BPs. As summed up by Wurzinger et al. (2011) for CBBPs, the only avenue to guarantee sustainability is that government priorities (at local or national level) emphasize community-based breeding as a viable alternative for smallholder improvement on a long-term basis, and that appropriate policies provide the enabling environment for realization and adoption at a large scale.

Without the creation of strong cooperatives to manage the BPs, help with funding and development of new technologies, efforts for scaling up or out are likely to fail. The success may stay at a small local scale and 'niche' markets. Implication of livelihood-supported institutions is also crucial when designing CBBPs and should help to empower local cooperatives to own and operate the CBBPs. A major component is the involvement of NGOs that have access to groups of very poor farmers (in general women), and provide micro-credit and training to help these groups establish small breeding units, with dedicated training for farmers, extension staff and animal products traders.

Despite the involvement of various types of stakeholders, challenges such as complex logistics, local/national political instability, distrust and lack of continuous external funding hindered the maintenance and expansion of the BP over time, after the research phase. In most countries, regular national/regional governmental funding is missing to provide sufficient support and extension services to smallholder and middle-class farmers. This last point has been consistently reported in all case studies. In cases where there is a strong involvement of CGIAR centers promoting innovation through coupled policies, technologies and capacity building for decades (such as in Ethiopia and Kenya), CBBPs can developed and be scaled out thanks to continuous technical supports from research centers and extension services, and sustained financial support provided by national governments, development agencies and leading private foundations. The necessary scaling partners are national agricultural research and extension services, international research organizations and universities, private companies – including farmer associations and industry sector, global bodies and regional bodies such as development banks, and international/regional NGOs.

As stated by FAO (2023) in its report on the state of food and agriculture, it is essential that the hidden costs of agrifood systems – many of them rooted in market, institutional and policy failures – are analysed, assessed and valued through rigorous accounting. This information has then to be used to reduce or avoid these costs while maximizing the benefits for the society. By integrating true cost of agrifoods) systems into everyday decision-making and management strategies, agrifood businesses can monitor and unlock opportunities at different stages of the supply chain, achieve sustainable production, attract private investment and avail of government incentives. When informed by targeted true cost assessments, existing levers in BP development, such as national or international subsidies, can be redirected or reformed to support and scale up promising and emerging strategies for sustainable businesses and investments. Genetic resources and food security are public goods, i.e. goods and services that are desired and appreciated by society, but which markets fail to provide. Therefore, governments need to step in with public support and regulation. In particular, supporting CBBPs is believed to be a way to guarantee for all the population a minimum level of decent income that can protect against poverty, food insecurity and malnutrition, i.e. a way to avoid distribution failures. Vagaries of political cycles can create certain policy failures as developing sustainable BPs requires investments that take time until their impact is felt on the field. Dispersed governance (often existing for management of land and natural resources) can also lead to policy failure for scaling up or out BPs, when the local level has some degree of separate political authority and can reduce the degree of consistency in policy delivery as well as its effectiveness at national and global levels. Last, but not the least, market failure driven by the complete absence of a product or service, such as insurance and credit markets often lacking for smallholder farmers in low-income countries, affects farmers' investment decisions and forces them to operate at a suboptimal level, with direct negative consequences for their food security and livelihoods, as well as for the adoption of technologies that enhance environmental sustainability.

3.3. Development and maintenance of a reliable data recording system

An essential component of any BP is to implement and sustain an efficient data recording system for the pedigree and performances of interest for breeding. Recording entails collecting and managing data on animal identification, pedigree, health, growth and other traits of interest. Various methods, from manual record-keeping to digitalization, can be applied. Regardless the type of the data recording system, it needs the full commitment of the farmers and extension agencies. Data collection and long-term storage is a challenge. Regular visits from extension staff are needed to ensure permanent high-quality data recording. A possible division of labour should be considered in the planning, and it should be determined which data should be collected by the farmer and which data should be collected directly by the extension service.

Therefore, an important condition is that financial support is secured for infrastructure development and other requirements emerging from the need to benefit more farmers, as well as human resources, e.g. the staffing of extension people to assist in the recording process. This can only happen if research and development actions are projected in synergy. As underlined by Wurzinger et al. (2011), the development programmes must provide the funding investments and the research programmes, the technical supervision and long-term support.

The availability of a research organisation willing to provide technical assistance and intellectual support on a long-term basis is, therefore, another key factor to consider. This might be very often difficult as research funding is often only provided on a short-term basis and researchers might have to shift to other activities, moved either by the institutional priorities focusing on alternative issues or by their personal evaluation procedures. Research organizations must institutionalize their willingness to participate in CBBP actions as an integral part of their institution's strategic development plan and priorities. This will ensure that due resources and academic staff will be allocated even within a turn-over of members, securing the sustainability of the commitments of research to the recipient communities. A critical role for researchers is to establish the documentation of all the BP processes followed with clear definition of data sources, staff involved in data collection and depositaries of this information. Implementation of data backup and security must also be considered. It is also important that a clear division of labour and responsibilities is drawn from inception between technical staff and farmers, and fully observed by the community. It should encompass the facilitating conditions that farmers have to provide during recording and their participation in the recording process. Data analysis and feedback to farmers are also key elements in the context of recording plans that have to be clearly documented and run on a routine basis. Farmers must objectively appreciate the benefits of what they are measuring. Without clear feedback, it is very unlikely that the recording plan will be continued and scaled up. Continuous improvement of the recording plan (e.g. new traits, technologies, software updates) is necessary which implies investing in the necessary tools such as digital tools and apps and providing appropriate training and support.

The practice of growth or milk recording enables farmers to monitor the productivity of individual animals and the overall herd, which helps as a valuable resource for informed decisions to improve the overall herd management. Under smallholder conditions, a very accurate and detailed recording might not be feasible, unless these activities are linked to market incentives. The aim should be to identify simple, cost-effective and time-saving recording schemes. Recording performance for growth is much easier to obtain than milk recording which requires detailed following-up and repeated measurements. In many cases, daily milk recording schemes are proposed, which are not actually needed, and their proposition may result in an impossible task for farmers or extension staff to collect data unless efficient digital tools based on the Internet of Things (IoT) can be used on mobile phone applications (Resti et al., 2024). The use of mobile phones is an appealing choice due to the widespread ownership of mobile phones in all countries. To enhance the advancement of these tools, it is, however, necessary to address technological obstacles, particularly those associated with access and connectivity (Resti et al., 2024).

3.4. Training of scientists and extension staff

As underlined by Wurzinger et al. (2011), the communication process between farmers and scientists / extension staff is of major importance for the success of a CBBP. To build trust among farmers, regular meetings, and feedback loops to discuss information and findings have to be incorporated in the BP design.

The issues for farmers are complex and do not necessarily focus on breeding aspects. Researchers and extension staff should help farmers to overcome all other technical, economic, environmental and social issues, which will create more trust and sense of partnership. Key resources like staff members with both knowledge in technical issues and participatory approaches are limited, as well as the availability of a R&D organisation, willing to provide technical assistance and intellectual support, i.e. in matters of backing data recording and analysis, and monitor that the principles applied are being kept. A large set of participatory tools is available, but these are not part of the knowledge background of most animal scientists, as these tools are not widely taught in educational centres.

In most cases, there is a need for researchers to be trained in the basics of participatory concept and process. Ignoring this fact could be the prescription for the failure of a CBBP project. Therefore, resources should be planned in this direction from inception. It is important to develop communication skills of scientists and extension staff for interacting with local communities. Emphasising in their capacity building the importance of involving livestock keepers in any decision making on policies or BP related to livestock is essential. This is especially important to find out new challenges faced by livestock keepers and how governments could help them to face these challenges and earn an adequate income from livestock rearing. As underlined by Ojango et al. (2024), two important points must also be highlighted: 1) change of behavior and reorientation of livestock producer's mindsets to entrepreneurship. These authors defined the entrepreneurial ecosystem as the set of interdependent actors and factors coordinated in such a way that they enable productive entrepreneurship. This must expand networks for services and market opportunities for animal offtake and introduce options for stratification in livestock production systems. 2) building the capacity for supportive ecosystems to create and improve productivity while maintaining diversity in livestock resources.

Conclusion

Breeding programmes can only be successful in the long term if cooperation between the various stakeholders works well and funding is secured. A prerequisite for their success is the existence of a market that can make profitable livestock breeding and products. Scientists' support is needed to assist stakeholders in their research and development actions as well as in their capacity building. The main issues that have to be addressed for successful implementation, sustainability and scaling up/out of BPs are:

1. Identification of the right partners and integration of farmers' participation in the BP planning, proposal formulation and evaluation process with BP goals set up in line with the national/local agricultural policies

2. Institutional support, including recognition and registration of well-organized breeding cooperatives of the members of smallholder livestock keepers

3. Ensure long-term technical support to the BPs from local or national research centres, NGOs, and extension services in data management, analysis and feedback of estimated breeding values from committed and accessible technical staff

4. Development of a simple, cost-effective and objective-oriented recording scheme with easy-to-use mobile applications for data collection and management

5. Establishment of strong market linkage for improved animals and products to ensure returns on investment and strengthening the financial capacity of cooperatives

6. Clear framework for dissemination of improved genetics and an up/out scaling strategy. Improved germplasm, whether in the form of live animals, semen, embryos or eggs, has to be produced and disseminated efficiently

7. Capacity building of the different actors in animal husbandry, breeding practices, data collection, breeding value estimation and sound financial management

8. Availability of complementary services like affordable animal health service for disease prevention and control and access to adequate and quality feed resources.

9. Periodic evaluation of ongoing programs for drawback identification and impact assessment to improve the BP, which should remain flexible and evolve with newly emerging challenges and farmers' feedback. Multi-stakeholder platforms ensure regular communication between all stakeholders and provide opportunities to review progress, provide feedback, align strategies and plan the way forward.

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Annex 1. Two initiatives in BURKINA FASO in link with the animal breeding company Hendrix Genetics (interview of Naomi Duijvesteijn, R&D director of SASSO and SAPPSA project manager)

In 2018, Hendrix genetics acquired 100% of SASSO, a specialized coloured broiler French breeding company. SASSO have the world's largest gene pool of traditional poultry, in particular slow growing broiler and dual-purpose breeds. Dual-purpose chickens provide small-scale producers with more eggs and higher weight birds in a shorter period of time than indigenous tropical breeds. SASSO slow growing lines were developed in links with the development of the Label Rouge chicken production in France in the 80s. Those lines were also better fitted to the tropical conditions of Africa, Asia and Latin America than standard commercial broilers. Nowadays, 70% of SASSO sales are in tropical regions. Through these SASSO lines, Hendrix genetics is focused on developing and supplying good quality parent stocks and chicks for egg and broiler producers in Africa. This world leading player in animal breeding is involved in the two projects dedicated to the implementation of sustainable breeding programmes in Sub Saharan Africa described hereafter.

1/ The 'Poulet du Faso' / 'Coq du Faso' breeding programme in Burkina Faso

Stakeholders motivations, breeding goals and strategy. This is an initiative founded by the Bill and Melinda Gates Foundation (BMGF) in collaboration with Ceva (Animal Health company) and SASSO in 2015 called: 'Coq du Faso'. In this programme, a local selected sire line 'Coq du Faso' is crossed with a SASSO hen to produce the 'Poulet du Faso'. The selection of the local sire line was undertaken by sourcing chickens from local farmers which were collected on a local breeding farm with the aim to improve the Burkina poultry breed referred to as the "Poulet Bicyclette" or Bicycle Chicken. Importantly, the phenotype of the birds (look like a grilled chicken with very long legs and darker and more flavoursome meat than the standard commercial broiler meat) has remained unchanged due to the aesthetic preferences of the Burkinabé.

The project set out to produce a cross-breed of these local chickens and slow-growth SASSO hens with greater production capacity to provide smallholders with more and healthier 1day-old chicks. The chicks are all vaccinated in the hatchery using Ceva's vectorised vaccines, which, according to the company, gives them life-long protection against Newcastle Disease, which is very prevalent in Africa. Mortality rate among Poulet du Faso is just 5% compared to 50% among traditional breeds. Furthermore, the crossbreed reaches market weight (1.2 to 1.4kg) in 75 to 90 days compared to the typical 6 months' rearing required for its local counterpart.

Description of the breeding programme. Ceva partnered with SASSO-Hendrix Genetics to breed the chickens at the first avian selection centre in sub-Saharan Africa, named 'Coq du Faso', located in the rural Boussé, 50km north of the capital city Ouagadougou. The selection centre was built with Hendrix Genetics' advices to set up the technical facilities. In 2015, farmers started their local breeding programme for the local sire line, taking from the fields the local birds from the different villages to place them in quarantine in the selection centre which is owned by a local cooperative of farmers of Boussé. BMGF also helped for the running costs for the first 5 years of the BP, but there are no longer any subsidies to run the local BP. The cooperative is not really doing extra-money, but it is self-sufficient and pay all costs for animals and salaries. As an extra incentive, people working on the farm get about 30 eggs/month and take some chicken home. In 2023, they were at the 7th selection generation of the local sire line at the 'Coq du Faso' selection centre (composed of a rearing unit and a production farm).

The birds are monitored in each stage of their life from hatch to reproduction in the cooperative farm. The 'Coq du Faso' program is with 30 sires and 250 dams. Candidates are selected on body weight, and records from trap nesting of eggs (egg production) and a full pedigree hatchery process, are used for breeding evaluation done by a volunteer geneticist. Hendrix geneticists still help a lot the local team to run breeding evaluation and do the right selection choices for the local sire line. Hendrix trained the two managers (the farm manager and the sales manager of 'Coq du Faso'). Hendrix is only supportive for that BP, does not hold anything, but Hendrix has a commercial agreement with the cooperative to deliver the dam stock and is paid for it.

Poulet du Faso is available as day-old chick vaccinated from Anipole Faso (a private distributor company located at Ougadoudou that collaborate with the Coq du Faso selection centre), intended for start-up and peri-urban breeders or 6-week-old starter chicken produced by starter breeders, vaccinated and ready for traditional backyard farming. The Poulet du Faso is recognizable by its wing ring indicating 'Poulet du Faso', which guarantees its traceability. Poulet du Faso chicken are sold for a higher price due to being locally produced. Restaurants pay for this label (good meat quality, vaccination against Newcastle disease). There is also an export market, in particular to Togo, and to a lesser extent, Ghana and Senegal. There is also an informal market for Poulet du Faso.

Part of the 1-day chicks are sold to specific farmers called « ambassadors », corresponding to mother units or brood units with specific guidelines ("heat the chicks, feed them well"). They are independent, but they are supported by the 'Poulet du Faso' value chain. These farmers are controlled to validate that they raise well the young chicks. At 5-6 weeks of age, the chicks are sold to smallholder farmers where they are only fed at 50% with commercial feeds, the other 50% comes from organic wastes and farm products.

Impact. In 2020, it was estimated that this project in Burkina Faso has allowed approximately 1,000 small-scale chicken farmers to increase their productivity 100-fold. (https://www.poultryworld.net/poultry/crossbreed-chicken-increases-production-100-fold/)

2/ The 'Sustainable Access to Poultry Parent Stock to Africa' (SAPPSA) project

Stakeholders motivations, breeding goals and strategy. The SAPPSA project (Sustainable Access to Poultry Parent Stock to Africa) , a Hendrix project funded by BGMF, was initiated to secure the supply of good quality parent stock genetics to African smallholder farmers (https://www.hendrix-genetics.com/en/about/our-company/sustainability-program/sappsa/). Parent stock refers to the breeders that produce the end-product birds (commercial birds) that go to the smallholder farmers. The SASSO grand-parental pure lines and breeding programme are located South of France. The SAPPSA project should ensure the bird is adapted for the local needs and environmental pressures in Sub Saharan Africa so that these birds will perform well for a backyard farmer that can therefore increase his income and grow his farm.

In 2018, Hendrix Genetics received a multi-year grant (2019 to end 2023, renewed in 2024) from the BMGF for the SAPPSA project with the objective to secure access of poultry parent stock, improve dual-purpose breeds for African smallholder farmers, and grow APMI ("African Poultry Multiplication Initiative") within and across countries. The way in which SAPPSA works is that it builds upon existing and established projects such as the APMI model that is led by the US-based World Poultry Foundation (WPF) and supported by BMGF. It operates on the simple basis of sustainable development by securing the chain between hatcheries, mother units, and smallholder farmers. In this model, hatcheries are responsible for hatching day-old chicks and giving vaccinations, mother units are responsible for raising the chicks to 4-week-old teen chickens, and smallholder farmers complete the chain by raising the teen chickens to adulthood. In the project systems are developed to support the local parent stock farm to improve performance at each link in the supply-value chain. Alongside, it also helps with supplying the local African members with education on best practices for nutrition, housing, and poultry biosecurity. WPF has developed a Brooding Manual and a series of online training videos to help emerging African poultry farmers learn poultry farming best practice and optimise their farming operations for production of healthy dual-purpose chicks.

Description of the breeding programme. Since the beginning of 2020, offspring of elite birds from SASSO dual purpose lines are tested either for growth or for egg production in SASSO facilities in Burkina Faso, in addition to the recurrent test in France.

- As an example, here is the SASSO sire line Ruby T BP design. Each year, 30 sires and 150 dams are used to produce the next generation. SASSO hatch ~1200 offspring and measure them for body weight and other traits at 8 weeks of age. The best 60 sires and 200 dams are selected based on estimated breeding values. When possible, SASSO will cross the males with another line of females (protection of IP) and produce offspring (>15 per sire) to be sent by plane to Burkina Faso and tested for growth under those circumstances.

Because SASSO is supporting the ‘Coq du Faso’ program, they have people trained in Burkina Faso for data recording and well-informed of the importance of breeding programs in the ‘Coq du Faso’ selection centre. The local team in Boussé takes care of SASSO recurrent test birds, but also guarantee reliable data recording (they are paid for that by SASSO). Phenotyping is done exactly the same way as in France, with the same devices. Weights are measured multiple times and because the birds have an RFID (sensor in their wing band), the scale automatically connects the weight and animal ID and stores this data. After the data is collected, the data is directly synchronized with the database in France so the data is available and safely stored within days of the time of measurement. SASSO makes the last selection step based on more accurate breeding values for those sires (and dams) for the trait tested in a recurrent testing situation (additionally the dams of these selection candidates have now completed their production cycle (trait egg production)) which results in an updated index. Finally, 30 sires and 150 dams are selected to produce the next generation sires, exclusively based on that field offspring test in Burkina Faso (regardless of own performance of the males in France).

- For female lines, SASSO also record egg production. For egg production small families are reared together (family cages: 5 half-sibs with the same sire) and egg production (for 30-40 weeks) is recorded on a daily basis as well as mortality of birds. All birds are reared in open houses, they have to face the challenging weather conditions. It is a bit more challenge to record egg production for female line in Burkina Faso (because during heat waves you do get no eggs as the hens are not eating) than body weight for the sire lines, but it has been done for the last 3 years (and it was done successfully for the last 2 years). Similar as for the sire lines, the best sires of female lines are selected from Burkina Faso’s field data.

Since end of 2021, the company Neogen who offers DNA testing and genotyping tools for livestock animals, has a partnership with Hendrix to support implementation of genomic selection in SAPPSA programme and enhance the SASSO existing recurrent test programme.

Impact. By testing pedigree lines under African conditions, the lines better serve African markets with dual purpose chicken. Over 300,000-400,000 parent stocks per year are sold to customers in Sub Saharan Africa to serve the rural African market.

Annex 2. Sheep Breeding Programme in Kenya and evaluation of its impacts (Interview of J. Ojango, senior scientist at the International Livestock Research Institute)

Stakeholders motivations, breeding goals and strategy.

The BPs (case 4) for the Red Maasai and Dorper sheep and the crossbreeding programme for their crosses were established in 2003 at the International Livestock Research Institute (ILRI) ranch in Machakos County of Kenya. The main breed groups in the breeding program comprised of pure Dorper (DDDD), pure Red Maasai (RRRR), 75% Dorper (DDDR) and 50% Dorper and 50% Red Maasai (DDRR).The main objectives of the programmes were to improve the productivity and profitability of sheep raised in low-input systems in arid and semi-arid areas of Kenya by combining the faster growth rate and meat producing ability of the Dorper breed and the resilience of the Red Maasai breed through crossbreeding, and to sustainably conserve the purebred Red Maasai sheep through selection for growth, adaptability and resistance to Haemonchus contortus. In addition, some communities improved indigenous sheep using RRRR and cross-bred rams (75% Red Maasai, ie RRRD) selected in ILRI ranch. ILRI improved crossbred rams and females were introduced to multiply the improved stock and to get better productivity initially than the one achievable from improved purebred red Maasai breeding animals.

Description of the breeding programme.

In Nyando, the project initially included just one specific area involving seven different villages with 30 households each. A total of 35 Red Maasai rams were introduced. They were then used to set up village breeding units where the animals were collectively raised. Farmers learnt how to exchange the rams over different mating periods to avoid inbreeding. ILRI staff selected households who were known to be the main breeders or people able to generate or multiply the improved breeds: these selected households were given both females and males. National extension personnel was engaged, trained by ILRI for running the CBBP and affiliated to the programme. In order to ensure continuity beyond the life span of the project, farmers were taught to have only certain marked rams with them. They were keeping basic records when they were grazing to know which rams had been actually used for mating. With time, the farmers learnt to collect the data themselves. In Isinya, an area closer to the ILRI Kapiti ranch, the farmers trained on sheep breeding by ILRI are also trying to expand their multiplication flocks, so that they are mirroring what ILRI is implementing now in its nucleus. The Kajiado county livestock department requested support from ILRI to help them to adopt a similar model at a larger scale across the county. Currently, requests come from a large number of counties and ILRI needs to find the financial and human resources to run training programmes in all the counties.

Impact.

Oyieng et al. (2022) demonstrated positive phenotypic and genetic trends for weaning and mature weights in all breed groups in the ILRI BP. Sila et al. (2021) evaluated the performance of improved indigenous sheep and goat breeds and their contribution to household revenues, five years after their initial introduction into low-input smallholder farming systems in two communities of the Nyando basin of Lake Victoria, covering 169 farms from Kericho and Kisumu counties of western Kenya. Alongside a community training program on livestock improvement, the performances of both local and introduced improved indigenous breeds of sheep and goats from ILRI ranch in the smallholder farms were monitored between 2014 and 2019 through extension personnel engaged by CCAFS (CGIAR Research Program on Climate Change, Agriculture and Food Security). All offspring born within the flocks were weighed by the enumerators using a portable hanging scale within one week of birth and, subsequently, every 3 months until the age of one year. Records on the performance and healthcare of the animals were collected through tools developed by ILRI using the “Open Data Kit” software (ODK: https://getodk.org/). Differences in weights for the Red Maasai x Dorper crosses and the pure Red Maasai sheep were not significant. The introduced Red Maasai sheep had superior growth rates compared to all other sheep breeds: at one year of age, they were 61% heavier than local sheep. The growth rate of the Red Maasai and Red Maasai x Dorper crosses was not different from that reported for these animals under the semi-arid environment of ILRI ranch (Zonabend Konig et al., 2017). The first motivation of data recording was to show the difference in growth performance between the improved animals and the local ones, and that even among the local ones, some were performing better than others (Sila et al., 2021). It was important to identify younger people from the households who could understand the use of tools and technology and that the faster growing animals should be kept rather than being sold to the market. Another advantage of data collection by the farmers is to avoid some bargaining with the marketers, for example by weighing the animals rather than guessing their weights. It is expected that the farmers themselves will support the recording process if marketers are using their records.

In addition to monitoring animal performance, a semi-structured household survey was implemented among the 169 households of the Nyando basin in December 2018 to determine the farmers’ perspectives on the performances of the introduced sheep and goats and their crosses with the existing local indigenous non-described strains, the costs of inputs and resources allocated to sheep and goat production, and returns from the animals over the last 12 months. Information on prices of inputs and animals were based on the farmers’ recall and verified through the extension personnel and national animal health service providers. The individual animal milk production was estimated by farmers with standardized metallic cups. The improved indigenous breeds that were introduced into the smallholder farming systems and their crosses with local animals exhibited improved growth rates, resulting in increasing the net returns from rearing sheep and goats. Results generated through the survey and performance monitoring were presented to the communities and reviewed in focus group discussions involving livestock keepers, extension personnel, animal health service providers, and county livestock production staff.

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Annex 3. A sustainable cattle and buffalo breeding programme for smallholders in India (Interview of Marimuthu Swaminathan, former geneticist at BAIF, Pune, India)

Stakeholders motivations, breeding goals and strategy.

Indian Dairy Sector. India is home to 15% of the global cattle population and 45% of the buffalo population. Livestock in India plays a multifaceted role, serving as a "walking bank" for smallholder farmers. The dairy sector, primarily managed by smallholders with less than one hectare of land, typically involves herds of 2-5 animals. Approximately 80 million farm families are engaged in dairy farming. Additionally, many farmers rely on other livestock species, such as sheep, goats, pigs, and poultry, for their livelihoods, employment, and food security. While dairy production is significant, it is not the sole income source for smallholders but carries substantial cultural importance and is integrated with crop farming in a mixed farming system.

In rural areas, cows and buffaloes are raised by smallholders who mainly rely on crop by-products and residues. These animals are sustained on a high-fibre, crop-residue-based diet, leading to low productivity, with an average of 2,000-3,000 litres of milk per lactation. Buffaloes contribute about 50% of India's dairy production. They have a longer lifespan of 8-12 years and produce 2,000 to 2,500 litres of milk per lactation with 6-8% fat content. However, the low-quality feeding systems, coupled with low productivity, result in higher greenhouse gas (GHG) emissions per kilogram of milk, with nearly half of India's methane emissions coming from the dairy sector. Given the need to feed approximately 1.4 billion people, a large portion of arable land is allocated to crop production, leaving only about 4% of this land for fodder production, which presents a challenge for high-quality forage production.

India is the largest exporter of buffalo meat globally, although domestically, meat from small ruminants and poultry is preferred. In many states, cattle slaughter is prohibited, which has led to the establishment of "Goshalas" (shelters for non-productive cows), often supported by philanthropic donations. With the rapid mechanization of agriculture, disposing of non-utility male cattle has become a significant issue. Male cattle are often neglected, unvaccinated, and abandoned, roaming freely in nearby forests or communal lands, which increases the risk of disease outbreaks.

Indian agricultural policy, particularly in the livestock sector, focuses on structural support for farming, including livestock management, animal health, forage production, cooperatives, and animal breeding efforts such as semen production and artificial insemination. The Indian Council of Agricultural Research (ICAR) oversees agricultural education and research, while state governments manage core agricultural strategies and policies, as well as education and research in animal science and veterinary medicine. Although stakeholder engagement exists, the decision-making process generally follows a top-down approach.

India officially recognizes around 50 cattle breeds and 17 buffalo breeds, some of which are rare and possess unique traits. For instance, the Chilika buffalo in Orissa is known for its resistance to saline conditions. The ICAR and government agencies support the characterization and conservation of these breeds. While pure draft breeds still exist, their numbers are declining due to agricultural mechanization. Additionally, there is a significant population of "non-descript" cattle and buffaloes that result from unplanned natural breeding.

Contributions of Key Organizations to dairy breeding. Central and State Governments, national bodies, cooperatives, NGOs, and the ICAR made great contributions for sustaining dairy breeding programmes in the country. Noteworthy to mention that two major organizations, namely, BAIF Development Research Foundation (founded in 1967) and NDDB (established in 1965), have been instrumental in developing artificial insemination delivery systems in India. BAIF operates in 13 states, assisting 4 million smallholder dairy farms, while NDDB has driven the development of India's dairy sector with a focus on cooperative development. In recent years, cooperatives and large private dairy companies have begun offering breeding services, feed, and credit to farmers, further supporting the growth of the dairy sector.

Description of the breeding programme.

Historically, state-run institutes-maintained nucleus herds of exotic and indigenous breeds, some established during British colonial times. While these herds initially thrived, limited selection criteria and inadequate breeding infrastructure, particularly in semen distribution, hindered genetic progress. Crossbreeding between Bos indicus (Zebu) and exotic Bos taurus breeds began in the 1970s, resulting in 30 to 35 million crossbred cows today, primarily Holstein and Jersey crosses with local cattle, although some use of Brown-Swiss has been recorded in southern India. These crossbred cows typically live for 8-9 years, compared to longer-lived indigenous breeds that are well-adapted to local agroecological conditions. There was also crossbreeding and upgrading of undefined buffalo populations with well-defined buffalo milk breeds. The crossbreeding in cattle and upgrading in buffaloes have significantly boosted milk production in the country. Increasingly, state and central government policies discourage the use of crossbred bulls on pure indigenous cows and recommend maintaining a 50% indigenous and 50% exotic blood level in crossbred populations (or up to 62.5% exotic blood in favourable climates). However, farmers often prioritize production levels, especially when they have become accustomed to higher milk yields from F2 crossbreds. The government's goal is to standardize sustainable breeding programmes across different breeds, particularly for crossbred animals.

Progeny testing, a method for selecting bulls based on their offspring's performance, was initially implemented but with limited scope, which resulted in production of inadequate numbers of genetically superior bulls for semen stations. A World Bank-funded project in the 2010s and implemented by NDDB in partnership with state governments, NGOs and cooperatives, aimed to expand progeny testing, focusing on crossbred cattle, Zebu, and buffaloes, contributing to the availability of large numbers of high-quality bulls.

More recently, genomic selection has been introduced for bull selection in indicus and crossbred populations. The National Dairy Development Board (NDDB), with the support of Danish scientists, and BAIF Development Research Foundation, in collaboration with the Bill and Melinda Gates Foundation and scientists from Australian (University of New England and University of Queensland) and French (INRAe) universities, have launched programmes to create a large reference population for genomic selection. This initiative aims to genotype around 100,000 animals and phenotype around 500,000 animals, establishing a common reference population for the country. The focus extends beyond milk production, incorporating broader traits like fertility, functionality, and adaptability.

Impact.

Although genomic evaluations are progressing, challenges such as managing male animals, improving the selection efficiency and reducing the generation interval in females persist.

India currently has about 56 frozen semen production centres. Various state and central government initiatives, along with cooperatives, national organizations such as NDDB, and NGOs like BAIF, have played a significant role in providing frozen semen and delivering artificial insemination services to farmers. The availability of liquid nitrogen, a byproduct of various industries, has made artificial insemination cost-effective. Measures are in place to control inbreeding, such as rotating bull semen in different regions every two years.

Annex 4. A goat governmental *versus* a community based-breeding programme in India and evaluation of their impacts (Interview of C. Nimbkar, head of Nimbkar Agricultural Research Institute)

Stakeholders motivations, breeding goals and strategy.

(1) The 'All India' coordinated research project on goat improvement is a centralized breeding programme of the Indian Council of Agricultural Research (ICAR) that started in the 1990s' for indigenous goat breeds. This was a transition from crossbreeding with indigenous improved breeds and exotic breeds in the 1970s to selective breeding. There are over 20 research centers involved in the 'All India' project for about 15 to 18 different goat breeds, but data management is not centralized and each center manages its own data separately. The Central Institute for Research on Goats of ICAR, which is the coordinating Institute for this All India project, have made several unsuccessful attempts to develop a centralized database since the end of the 1990s'. In addition, the 'All India' project is operating in a system where a lot of the participants are maintaining goats for subsistence. So sometimes it happens that after a selection of 7-8 years, farmers sell their whole flock.

NARI is the only NGO involved in this project (since 2009) for the Osmanabadi goat breed in Maharashtra. Field performance recording is done on smallholder farms, but NARI is only working in 1 village in each district (in five districts of Maharashtra) due to funding constraints. Fast-growing twin-born selected male kids born to does with comparatively higher milk yields are brought to NARI center (Nimbkar Agricultural Research Institute in Phaltan, Maharashtra) when they are 6 months old. They are reared there until they are sexually mature, then their semen is collected and frozen (some AI technicians regularly buy semen from NARI) and the breeding bucks are sent back to the villages. NARI also supplies semen straws to trained *Pashu sakhis* (women friends of animals) with the NGO Manndeshi Foundation who provides a goat AI service at the farmer's door in 250 villages in five districts of Maharashtra. Because of the limitations in the 'All India' program, NARI researchers are not able to access more genetic variation by enrolling more villages and different areas in the breeding programme. NARI has developed its own database for the breeding programme, but it is not cloud based (data are kept in an SQL-server based database) and it is not accessible to anybody else.

(https://idc.icrisat.org/idc/wp-content/uploads/2019/01/Flyer-Osmanabadi-Goats-Final.pdf
https://pcgoatcirg.icar.gov.in/osmanabadi/pdf_download/Osmanabadi%20Goat%20Breed%20Status%20Paper.docx)

(2) The community-based breeding program in Project Mesha deals with about 50 000 women that are black Bengal goats keepers in Bihar state. The CBBP was implemented in 2018 by the Aga Khan foundation (AKF) with technical consultancy by NARI and AbacusBio, NZ and financed by the Bill and Melinda Gates Foundation for 5 years. AKF is recording animals in about 18 villages in four blocks of Muzzaffarpur district of Bihar. In the Bihar project, there is a cloud-based database and the workers on the field can enter the data into the database and can also access the data at any time.

Description of the goat CBBP in Bihar state.

Project Mesha select male kids are raised by the women as breeding bucks that are purchased by buck entrepreneur women in other villages. The buck selection is based on an index that encompasses the average daily gain and body score of the kids until the age of 100 days and the litter size history of the dam of the buck. A doe with twins is preferred to a doe with triplets or quadruplets. There are 18 recording villages which produce the breeding bucks, which are then supplied to about 50 other villages. The project has a veterinarian that tag the kids and "para workers" who visit 2 or 3 villages 2 or 3 times a week and record the number of kids born and weigh them and enter the information in the database (supplied and operated by AbacusBio Ltd. New Zealand). Ear tagging is always a challenge because the animal owners don't really like to have tags on their animals. There were a few mistakes in the beginning of the project where the ear tags came out, tearing the ears of a couple of goats in some villages. Working in these villages was not possible after that, because the villagers were so against the use of ear tags. The breeding decisions are taken within the community and limited to the choice of the breeding buck for the whole village or a group of farmers (most families keep only two or three goats). The buck is bought for the whole village or for a group of farmers in a section of the village. All farmers contribute to buy the buck and then they designate one person who will actually look after the buck. The buck keeper gives the others two free services and then the buck keeper starts charging them money after the second time and, if there are any people from outside that section of the village who bring their goats, then they have to pay so that the buck keeper can cover the cost of feeding the buck. Currently about 100 breeding bucks are used for natural services.

Impact.

Due to adequate funding for the last five years, the Bihar project is also making considerable efforts towards organizing the communities of goat keepers into producer groups with the perspective to continue a self-sustainable and economically viable CBBP after the research project is over. Huge efforts are also done for capacity building with the training of rural village women (*pashu sakhis*) in i) administering vaccines and deworming medicines to goats, ii) castrating the surplus goats which are not selected for breeding, and iii) organizing marketing. The project which started this CBBP is still going on, so the project staff members are there, in the villages. In order to foster self-reliance within the community, AKF supported the formation of an all-women goat rearers’ producer company (Mesha Mahila Bakri Palak Producer Company Limited) with more than 3000 members, formally registered in August 2024. The sale of goats, kids and breeding bucks is now being organized by the Company. The Company also provides good quality inputs such as vaccines, herbal medicines and concentrate feed mixture for goats through entrepreneur *pashu sakhi*s. Now the company is negotiating with outside development agencies which want to distribute improved goats and bucks in their own area. These agencies have been buying bucks from the CBBP at a higher price than the price paid within the community. So, the community members are benefiting from this income.

The Bihar project has a much more comprehensive, beneficial and holistic approach compared to the ‘All India’ coordinated research project. In addition, the Bihar state has a “rural livelihoods mission” called JEEVIKA which is operating on a much larger scale (20 districts), taking advice from the Aga Khan Foundation to check whether it will be economically viable to start similar schemes in the 20 districts. Currently the project is going on in one district but the state government programme may be able to have it happening on a much larger scale. The project staff are just at the stage of figuring out how it could become sustainable in the future. For example, if the project comes to an end, who is going to pay the fees for the maintenance of the database, when people have not experienced the benefits yet? (Since early 2024, the project has stopped paying the fees for the database; the managing director of AbacusBio is personally paying the fees and has agreed to pay them as long as data recording and purchase and placement of bucks continue.)

Annex 5. A local chicken breeding programme implemented by a Thai university (literature review and interview of Amnorat Molee, associate professor & researcher, Suranaree University of Technology, Thailand)

Stakeholders motivations, breeding goals and strategy.

Thailand is a major producer and exporter of poultry meat. The growth domestic product (GDP) is essentially due to large private enterprises. Thailand's private sector consists of a limited number of large enterprises in the broiler and layer chicken industry, when compared to several millions of smallholder and medium-scale farmers involved in the sector. Broiler chickens made up the largest number of animals in livestock farming in Thailand, which amounts to around 1,994 millions broilers per year. This was followed by layer hens, with 51.5 millions layers per year. From an economic perspective, broiler meat is the most important poultry product, both for domestic consumption and export. As in many other countries, egg production from layers is mainly for domestic consumption. Most chickens originate from parent and the most of grandparent stock imported from the United States of America and the United Kingdom. In the past, broiler development in Thailand was largely due to the private sector. However, as a result of the increasing importance of international trade of livestock (especially poultry), the Department of Livestock Development (DLD) set in 1999 farm standards and various regulations on animal welfare to ensure compliance with the European Union's regulations and requirements. After the highly pathogenic avian influenza outbreak in 2004, the government added measures which, in practical terms, required that all broiler farms producing birds for export had to be transformed into closed farms (i.e. use evaporative cooling houses). As such a transformation required substantial additional capital investment, the government actions, arguably, favoured large scale modernized farms. Since then, Thai poultry industry has been moving towards vertical integration in order to ensure compliance with requirements for food safety and animal welfare on export markets, a decisive driver being the ban of frozen broiler meat from Thailand by most importers. While the large Thai companies have been able to switch their production towards precooked products and cope with the new regulations for biosecurity, many smallholder broiler farmers appeared to be left out and stopped poultry production (FAO, 2008).

As a response to the 3 issues of food security, smallholder farms and loss of native genetic resources, Suranaree University of Technology (SUT), DLD, and Thailand Research Fund decided 10 years ago to collaborate on an academic BP development in order to create a native meat type crossbred chicken line beneficial for Thai smallholder farmers. A productive female line selected by SUT was crossbred with the native "Leung Hang Khow" breed because most of the crossbreds have yellow skin and shanks, that are more preferable for the Thaï consumer. This crossbred line was named the Korat chicken, Korat being the ancient name of the Nakhon Ratchasima province where SUT is located. Initially, SUT researchers started the project with a market survey and discussion with food services and farmers. The well-defined breeding goals were to improve meat texture and flavour while keeping competitive the cost of broiler production. Now, selection is focussing on feed efficiency (FCR) and meat texture to increase smallholder farmers' income (Katemala et al., 2021, Poompramun et al., 2022).

The ultimate goal of SUT is to increase the number of poultry breeders. Currently, there are 2 farms which raise parental stocks and produce 1-day old chicks. Some failure happened in the past probably due to different goals in a previous group of farmers. Despite the fact that farmers were trained, they do not keep on collecting data records after a while without regular visits from SUT staff. Currently, there are not enough extension staff to extend the programme.

Description of the breeding programme.

The BP is conducted by trained staff in SUT in well- equipped buildings for the parental stocks and production farm. SUT farm has a rearing unit and hatchery facilities. The crossbreeding programme is based on two breeds of grandparent stocks with 800 females reared for each of them with traced pedigree and recorded data (individual body weight and egg production). The male line is a native colourful breed ("Leung Hang Khow"), which is kept unselected by DLD, while the female line is a synthetic line created at SUT by initially crossing commercial broilers and laying hens. There had been more than 10 generations of selection for SUT female line with a breeding objective focusing on egg production, and now the line is stabilized to 200 eggs per hen per 52 weeks, just avoiding inbreeding increase. The parental stock is composed of 3000 SUT females with 5 females mated per Leung Hang Khow male to produce Korat chicks in the SUT farm. Korat chicken is growing very slowly in comparison to commercial broilers (1.2 kg after 2 months and FCR=2.3, versus 2.8 kg in 6 weeks and FCR=1.6). Volatile weather conditions, which contribute to the outbreak of diseases, are a threat to this poultry production system in open-houses.

The BP budget is funded by national granting agencies and SUT, and manage by SUT farm, a social enterprise unit that supports students and trains smallholder farmers. The government pays the permanent academic staff from the university and partly from the SUT farm. Students use the farm for practical learning and conduct research for master or PhD thesis. Moreover, some of graduates create their own farm with Korat chicken. There is also an on-line non-degree course open to anyone on how to breed, manage Korat chicken, including nutrition, nursing, food technology, how to use information technology to improve efficiency of production, and market studies.

Impact.

In the SUT farm, 50 000 chicks are produced each month and sold at 1 day old to about 200 smallholder farmers (rearing 100 to 1000 chicks while the medium scale farmers in North-East of Thailand have up to 10000 chicks). Currently there is no delivery service, farmers have to come and buy the chicks at SUT. The direct link between SUT staff and farmers limits Korat chicken to a 'niche' market, impaired by higher prices than regular chicken. The chicken meat penetrates to high end market both in food services and shopping centres under collaboration with private company name Betagro Public Company Limited.

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Annex 6. Zebu Dairy Breeding Programmes in Brazil, evaluation of their impacts, and prospects (Interview of MGCD Peixoto, scientist at EMBRAPA – Embrapa Dairy Cattle)

Stakeholders motivations, breeding goals and strategy.

Dual-purpose Guzerá and Dairy Gir are both *Bos indicus* breeds originated from India, which are major for dairy production in tropical conditions of Brazil. In the ~ 80s, several initiatives took place in Brazil to improve milk production in tropical and subtropical areas where small and medium-sized farmers with pasture-based production systems predominate and in which is more obvious the lack of adaptation of the high-yield Holstein cows. Several breed compositions of Holstein x Gir (including the synthetic Girolando breed) or Holstein x Guzerá were then promoted to farmers to improve production in harsh environments, keeping in some cases dual production objectives (dairy and beef). This initiative opened the possibility to start breeding programmes (BPs) in these *Bos Indicus* breeds, with later great commercial impact to those breeds (Madalena et al, 2012).

The breeding organizations are breeders' associations. As such, the Brazilian Association of Zebu breeders (ABCZ) is responsible for data recording in purebred herds, Zebu breed promotion, and the Zebu Genetic Improvement Program, PMGZ). The Brazilian Association of Dairy Gir Breeders (ABCGIL), the Brazilian Center for the Genetic Improvement of Guzerá (CBMG[2]) and the Brazilian Association of Girolando Breeders (ABCG) are responsible for collecting data from collaborating herds (usually crossbred herds) and for promoting each breed in particular. All of them are under the supervision of the Ministry of Agriculture, Livestock and Food Supply (MAPA), which initially funded the BP with the technical support of FAO.

Description of the breeding programmes.

The Brazilian Dairy Gir Breeding Programme (PNMGL) was established in 1985, based on a close partnership between the Brazilian Agricultural Research Corporation and the Brazilian Association of Dairy Gir Breeders. It was the first breeding program outlined with a progeny test for the improvement of an indicine breed for milk production in the world. The first Dairy Gir sire summary was released in 1993, and since then the results of accurate genetic evaluations of each battery of bulls have been annually published. PNMGL implemented the genomic evaluations in 2018, which has led to even more significant genetic gain. In 1994, the Brazilian Center for the Genetic Improvement of Guzerá, also in partnership with Embrapa Dairy Cattle, implemented the National Programme for the Improvement of Guzerá for Dairy Purpose (PNMGuL). This program was based on both a progeny test and a multiple ovulation and embryo transfer (MOET) nucleus schemes. The joint strategy aimed at promoting an initial genetic lift and rapid genetic progress in milk production traits, using accurate estimated breeding values. The first Guzerá sire summary containing the results of accurate genetic evaluations was made available in 2000, and an evaluation of the impact of the open MOET nucleus in the results achieved in the PNMGuL was only recently performed. In 2022, the MOET nucleus was closed and the program is now based solely on progeny test and, recently, genomic evaluations were implemented.

During the public presentation of the annual sire summaries (workshops dedicated to breeders), the technicians from the breeding associations and researchers from Embrapa Dairy Cattle and universities give presentations to facilitate knowledge transfer. The field technicians are usually trained every two years. The researchers also organize yearly workshops to talk about the BPs and to encourage new research demands.

Impact.

In the PNMGL, average milk yield of participating herds has considerably grown since the beginning of the BP, from 2000 kg in 1990 for the 305-day milk yield to over 4500 kg in 2021 (Panetto et al., 2022). In the PNMGuL, the annual phenotypic increase for milk yield revealed favourable improvements of 41kg/year and 98kg/year for the whole population and the MOET nucleus, respectively (Peixoto et al., 2022). The genetic trend for milk production for the whole population (5.27 kg/year) was positive, but notably lower than the genetic rate for the MOET nucleus population (9.39 kg/year). The average for the 305-day milk yield of participating herds increased from 2261 kg in 1994 when the Guzerá BP started to 2910 kg in 2022 (Frank T. Bruneli, personal communication, 2024).

In general, the breeding associations do not estimate the economic costs, gain and income of their breeding work. In the past, the economic instability of the Brazilian currency made it difficult to establish economic weights. Nowadays, the lack of economic records on farms brings difficulties to develop economic selection indices and, consequently, impacts the economic efficiency of these BPs. However, Embrapa analysts evaluate the costs and benefits of the BPs under its technical responsibility for internal usage, or only for the access of the MAPA. A sample of herds participating in each program is visited for data collection. The metric considered is the Economic Rate of Return (ERR), to show how a BP's economic benefits compare with its costs, looking at the impact of the use of "proven bulls" on the increment of herd productivity and the added value of commercialized animals considering all the benefits in the beef or dairy value chain. The last evaluation was carried out in 2021 for Nelore, Girolando and Guzerá breeds, estimating ERRs ranging from 13% for the Nelore beef BP and 78% for the Guzerá BP to an impressive ERR of 155% for the Girolando BP.

Due to the payment criteria, based mainly on volume, farmers prioritize milk production. But Brazilian legislation on milk quality as well as the pressure of dairy industry, also driven by the new consumer demands, is changing this scenario. As a result, many industries started to pay for milk solids content and quality, leading farmers to search for the improvement of fat and protein contents, as well as of the udder health. Other traits, such as those related to reproduction, growth and development, morphology, and disease occurrence (tick resistance), important in tropical and harsh environments with like-savannah and semiarid regions are beginning to be considered in BPs. However, data recording is hampered by the high costs of carrying it out in a country of such dimensions. They were not recorded in the Guzerá MOET Nucleus due to financial and logistic circumstances. Information on the beef traits of the Guzerá breed, for instance, is processed in specific genetic evaluations for beef cattle, carried out by beef improvement programs. However, as the database is genetically connected to the database of the milk program, the joint availability of genetic values for dual-purpose bulls is allowed. There are concerns about the necessity of not only enlarging the database for milk and beef traits in Zebu improvement programs, but also implementing phenotyping for adaptive traits such as feed efficiency, thermotolerance and disease resistance traits, to indirectly minimize environmental impacts in economically viable systems.

Breeding associations have access to media (TV channels, magazines, web etc.) aimed at the rural sector. They frequently use these channels to clarify questions not only to the sector but also to the population in general. Recently, it has been necessary to answer questions about animal welfare and environmental pollution. The research institutions also promote events with the same purpose.

The Low Carbon Agriculture Program (ABC Program) drawn up by MAPA was implemented in 2010 focusing on a sustainable animal production and mitigation of GHG. Beef farms are adopting many procedures, including intensification and welfare practices. Traceability protocols are also being developed. There is a growing concern about the importance of sustainable livestock to meet the global demands of society, consumers, and to be a player in the international market, but it has not yet reached all the Brazilian regions and farms. Nowadays, there are a lot of certifiers in Brazil to achieve the meat exportation rules/barriers, ensuring Brazil remains a leading player in the international meat market. Beef cattle is on the right track, boosted by exports. But there is a long way to go for dairy cattle: low levels of technology adoption and of good health and welfare practices, as well as lack of manpower and training resulted in low productivity and income in the dairy sector. Besides, the Brazilian dairy chain is facing a conflict with government policies, with importation of cheaper milk from other countries.

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Annex 7. Pig breeding programme in Haiti and evaluation of its impacts (from reports and literature)

Stakeholders motivations, breeding goals and strategy.

The BP (case 14) for the rustic Haitian pig started in 1986 at the initiative of the MARNDR (Ministère de l'Agriculture, des Ressources naturelles et du Développement rural) and the French Cooperation Ministry, after arose convergent analyses from French and Haitian NGOs and associations which gathered hundreds of thousands of family farmers. It was aimed at providing rustic black pigs to small farmers, after eradication of the local Créole pig population to control a massive African swine fever outbreak at the end of the 70's, and introduction in 1983 of improved exotic pig breeds from North America (Duroc, Hampshire, Yorkshire…), not adapted to the low-inputs small farmer contexts.

The pig population was built on a maternal line and a paternal line. The maternal line was a cross between Chinese pigs (Meishan or Jiaxing breeds) and the Gascon local French breed. The paternal line was issued from Créole pigs from the French west Indies Island Guadeloupe. These breeds had black color, as the original local breed, good rusticity potential to face heat and limited feed resources, together with maternal qualities for the maternal breeds and good sanitary status.

Description of the breeding programme.

The programme was initiated with one primary center in Thomassin for selection (PCS), where the lines were established, and would be maintained and selected. This site is at moderate altitude, therefore less impacted by heat. Secondary multiplication centers (SMC) were driven by NGOs (originally mainly to disseminate the Créole sires) or driven by the project (disseminating both lines). Finally, farmer organizations and individual farmers bought and raised the final crossbred animals. The first 5-years project supported by the French cooperation programme ended in 1991, with about 15,000 pigs in the PCS and SMCs, and 30,000 pigs from the first and second generations of pig crosses in the farms. The objective of 10 piglets weaned per litter was reached in Thomassin (Delate et al, 1989). It should be noted that few tens of thousands of pigs were also raised as uncontrolled crosses between one of those lines and the exotic lines imported via the North American programme and raised by larger scale breeders.

After interruption of the programme from 1991 to 1994 that stopped the PMC and some SMC activities, a new project supported by the BID (international bank of development), French cooperation and EU started in 1994 to re-establish SMC, produce breeders in the PCS in Thomassin and to develop a full pig production system including all stakeholders of the value-chain. This programme was run by a temporary consortium of institutes and companies (CIRAD, BDPA, FERTILE). The project sustained the prices of pigs sold by the PMC (breeding animals) and SMC (crossbreds), that could sell their pigs at fix affordable prices, and provided, in coordination with the ANDAH (national association of Haitian agro-professionals), technical support to the SMCs, with six persons specifically hired.

Initially, the pig population was established with rules to manage the genetic diversity in the lines, retaining sires from different litters and mating animals from different families. Then, mass selection was applied, on the color (only black animals), number of teats (>10), lameness, and prolificacy (piglets retained from prolific sows and litters with numerous piglets), and shape and growth.

Impact.

The main difficulties arose from communication issues (some SMC could not communicate by phone when problem arose), feeding difficulties (low and highly variable feed quality from local markets could not always sustain pig growth and reproduction in SMC, and performances in the small-holder farms were limited), new outbreaks of the African swine fever in 1996, that prioritized sanitary actions over genetics. Good quality feed had to be imported, so feed costs were too high for the programme to reach autonomy: in a survey, 90% of the SMC actors indicated they would not survive without funds, but 50% (Mainly related to NGOs) announced that they would continue anyway, as piglets from SMC were generally more robust than when born on the small farms. Finally, local groups had difficulties to gather and get organized to put together all the necessary elements of the production system (sanitary surveillance, regulation and training, slaughterhouses…).

However, towards 1998, 43% of the multiplication came from Thomassin, and the rest from 15 SMC, 12 having a formal contract with the project holders. From this, about 32,400 piglets are assumed to have been produced from 1995 to 1998, resulting on a contribution of 15,000 pigs per year to the farmers level. In regard to the ~700,000 pigs of the island it is relatively low, but contributed to local production, food security of small farmers, and to re-install local rustic animals.

Annex 8. Sheep breeding programme in Uruguay (Interview of Dr G. Ciappesoni, INIA)

Stakeholders motivations, breeding goals and strategy.

The total number of sheep is around 6 to 7 million animals. This number has decreased in the last 15 years (around 25 million sheep in 1995) due to wool price fluctuations and varying demand (heavy or light depending on the countries where they are exported) for lamb. Each breed has its own association, all of which are part of the ARU (Asociación Rural del Uruguay). Genetic evaluations, since 2002, are conducted by INIA (the National Agricultural Research Institute of Uruguay), in collaboration with the Uruguayan Wool Secretariat (SUL), which is funded by a tax on wool exportation. INIA has a similar agreement, 50% funded through a tax paid by farmers and 50% funded by the government. The evaluation covers various breeds, including wool or meat specialized breeds and dual purpose (wool + meat) breeds: Corriedale, Hampshire Down, Highlander, Polwarth (Ideal), Ile de France, Merilin, Merilin plus, Australian Merino, Dohne Merino, Poll Dorset, Texel, and Romney (https://geneticaovina.com.uy/).

The use of sheep breeds depends on climatic conditions, with significant variations between the north (more extensive farms) and the south (more intensive farms). The breeding goals are collectively defined through workshops involving breeders, commercial farms, industry representatives, and institutions. Bioeconomic models help determine economic values for traits, leading to the creation of selection indices. During workshops, usually the three best options of selection indices are presented; breeders are more interested in the process than the final decision and usually they trust INIA and SUL proposals. The breeding goals are nowadays more focus on incorporating agroecological goals, working on traits like feed efficiency and methane emission. Indeed, thanks to projects (GrassToGas, SMARTER, Sustain Sheep) and INIA funding, many traits are nowadays recorded in farm and or INIA facilities as faecal egg count, foot rot, reproduction trait, reproduction traits, feed intake and methane emission. Feed intake and methane records began in 2019 with experimental flocks (nucleus) from INIA and then in 2022 were extended to commercial rams of various breeds (Corriedale, Australian Merino, Dohne Merino, Texel and Merilin).

Description of the breeding programme.

In total, all the sheep BPs comprise around 80-90 stud flocks. The number of flocks (6-20) and the average number of ewes per flock depend on the breed: around 150 and 250 for Corriedale and Merino respectively while flocks of meat specialized breeds as Texel are smaller but reach a minimum number of ewes of 50 that allows to achieve the connectedness between flocks. The BPs rely on the active participation of breeders who are in charge of supplying data to the official genetic database through a software called "SULAR" developed by SUL. Additional data are provided by laboratory (e.g. wool quality) or INIA (e.g. ultrasound measures, feed efficiency or CH_4 measurements). The cost to breeders is approximately $100 plus $1 per ewe, plus the cost of specific analyses as faecal egg count or wool quality. From 20 to 25,000 new additional animals are included in the evaluation each year (lamb and ewe lambs). Pedigree record was a tradition for many breeders and within flock mass selection was set up in the in the mid-1950's. Across flock genetic evaluations were set up by INIA and SUL in 2002. A connectedness index derived from the blupf90 family program is calculated to check the connectedness between the different flocks. Nonconnected flocks have only within farm evaluation. The responsibility to maintain connections lies with the breeders but support is provided to breeders to improve their genetic links to other flocks. Artificial insemination is used with fresh semen, and frozen semen is also imported (except from UE for sanitary rules). Although breeding goal is set collectively, the breeding decisions, including mating plans, remain private, with no collective management of diversity.

Impact.

INIA together with SUL collaborates closely with breeders, and education programmes have been initiated, including teaching groups (about genetic evaluation, connectedness, genomic selection, …) and certification tests. INIA offers prizes at events like Expo Prado to encourage genetic improvement. They also communicate information about breeds through a website dedicated to sheep BPs. The success of the breeding programme is monitored through genetic trends expressed in dollars, and the breeding goals are re-evaluated every ten years. No information of dissemination through commercial breeders is recorded in databases.

According to the national livestock survey 2016 and an INIA query, it is estimates that 40 to 45% of commercial breeders used Expected Progeny Differences (EPD) to buy rams. This percentage varies widely between breeds.