Application of ICT tools and genomics technology for the transformation of dairy cattle genetic improvement in Ethiopia: ADGG approaches, experiences, and prospects

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Abstract

Dairy farming in Ethiopia is constrained by lack of a sustainable breeding program to generate and deliver tropically adapted high producing breeds of dairy cattle. Artificial insemination (AI) has been extensively used over many years. However, lack of a performance recording scheme has limited follow up and monitoring of calves born. The AI system is unidirectional mainly focused on the supply of semen and service of animals. A sustainable breeding program requires continuous field data recording, analysis and selection of top-ranking bulls and cows for breeding. The African dairy genetic gain (ADGG) program was initiated in Ethiopia and Tanzania in 2016 to introduce and advocate the use of information and communication technology (ICT) and tools for capturing performance data of animals, providing feedback and extension messages to support better farm management, and integrating genomic technologies in the selection of animals with the best genetic merit for desired productivity traits within the targeted environments. In Ethiopia ADGG is implemented in 6 regional states and 98 districts. The ADGG program established a national dairy cattle data base and requisite tools to enable real time on and offline data capture. Besides, selected dairy bulls and cows are sampled to determine their true genotypes. Since the start of the program 72,000 farmers and 116,000 animals are registered in the data base and 279,000 test-day records captured have been collected, and 6,800 animals have been genotyped using the 50K bovine SNP chip. More than 9 million education extension messages have been sent by ADGG to farmers via SMS in the last four years. The genomic and phenotypic data collated was used to evaluate and rank dairy animals from the different farming systems based on genomic estimated breeding values obtained through a so called single-step genomic evaluation model. Top ranking animals identified were published in a catalogue and paraded in the first national dairy animal parade held virtually in March 2021 and the best bulls were purchased by NAGII for semen production. National capacity to sustain the breeding program has been enhanced, with requisite infrastructure for continuity. It is evident that with the correct policy framework, government supported interventions implemented in collaboration with private sector actors, a sustainable dairy breeding program in Ethiopia can be catalyzed. Interventions initiated need to be scaled up through institutionalization of the breeding activities initiated, and continuous capacity building, engaging a wider category of private sector actors and supporting the building of partnerships among these actors in the dairy value chain. Animal identification and registration systems in the country need to be harmonized and farmers encouraged to

continuously record performance data on their animals with relevant feedback provided for improved productivity and informed decision making.

Keywords: Dairy, ADGG platform, Genomics, ICT tools, Data capture, Feedback

Introduction

Milk production in developing countries, including Ethiopia, is dominated by smallholder dairy farmers, each keeping 1-3 dairy cows. Majority of these farmers are not currently extracting optimum benefits, because herd and cow production and productivity levels are low (Shapiro *et al*, 2017). About 95% of milk produced in Ethiopia is from local breeds (CSA, 2019) which are kept by smallholder farmers under an extensive management. However, demands for milk and milk products is increasing and meeting the increasing demand for milk and dairy products cannot be realized without rapidly increasing the following: the number of high producing tropically adapted dairy cows, the number of commercial dairy herds, the number of cows per herd and productivity per cow (Shapiro *et al*., 2017). To narrow the gap between the projected demand and supply of milk and milk products, milk production per cow needs to significantly increase. To achieve this, the challenges facing smallholder dairy systems which include little or no systematic and sustainable breeding programs, limited access to the dairy genetics or breed types/choices that best suit the different production systems, inadequate access to various services and inputs, and access to information or farmer education and training services, must be addressed. In Ethiopia, genetic improvement of indigenous breeds through crossbreeding via artificial insemination (AI) started more than 40 years ago. However, the number of improved breeds in the country is currently only 2.34% of the total cattle population (CSA, 2019). This number is too small to support or help realize commercialization of smallholder dairy production. The high variability in milk production within the local breed cows (Yohannes *et al*., 2002) and among crossbred cows could be effectively exploited through selection.

Past genetic improvement for milk production by research institutes and universities has so far, mainly focused on evaluation of crosses of exotic dairy breeds with indigenous ones (Demeke *et al*., 2004) and most of these studies were based on multi-year data collected in research centers under herd managements that were different from the smallholder farmers' management systems or environments. Due to the free grazing management, smallholder farmers breed their cows

with uncertified local bulls which are in most cases inferior in performance because of castrating vigorous bulls for draft power. The ministry of agriculture has been using and promoting Holstein-Friesian and Jersey semen for crossbreeding with local breeds. However, data on the artificial insemination service has not been routinely captured and analyzed, hence the performance of the resulting crossbred cows under smallholder farmers' management and conditions have not been comprehensively assessed. Lack of record keeping made monitoring and subsequent inseminations difficult and resulted in crosses with very high (average 78%) exotic dairy breed blood level (Strucken *et al*., 2017) which do not match the farmers' management conditions, resulting in underperformance of the dairy animals, high cost of production (feeding and health care) and high risk of animal loss.

In Ethiopia, genetic evaluation studies in which lactation milk data (Demeke *et al*., 2004) or test-day milk records (Gebreyohannes *et al*., 2016; Meseret *et al*., 2015), collected from progenies across years, have been undertaken. To achieve estimated breeding values of adequate accuracy and reliability (Wiggans *et al*., 2011) and to have sustained genetic gains, these genetic evaluations and methodologies require continuous recording of pedigree and phenotypic data which is costly, and time consuming. African Dairy Genetic Gains (ADGG) (https://africadgg.wordpress.com), working in collaboration with national animal genetic improvement institute (NAGII) and the Natural Resources Institute of Finland (Luke) have developed and are implementing a performance recording systems that employs ICT tools and genomic technology to capture phenotypic and genomic records from herds kept by smallholder farmers, and medium scale dairy farms. The data generated is used to define more robust breeding objectives, develop realistic selection indices and the latter eventually used select top ranking bulls and cows for breeding under local production conditions. Working with a partner program, the Public-Private Partnership for Artificial Insemination Delivery (PAID), led by Land O' Lakes Venture 37, appropriate dairy genetics is being promoted. This paper shares and presents lessons drawn from the experience of ADGG in Ethiopia, its prospects, and challenges for sustainability and scaling up.

African dairy genetic gain project

Project vision goals and objectives

The African Dairy Genetic Gains (ADGG) https://africadgg.wordpress.com/category/adgg/ program is a farmer and country-focused International Livestock Research Institute (ILRI) led project, funded by the Bill and Melinda Gates Foundation (BMGF), which has been piloted in Ethiopia and Tanzania since 2016 and is recently being scaled in Kenya with plans for implementation in Uganda and Rwanda underway. ADGG was initiated with a **vision** to see that African smallholder dairy farmers are continuously accessing more productive dairy genetics, breeding and farmer education services and other related input services enabling their farming enterprises to be profitable and competitive businesses. The **goal** is to establish working systems based on public-private partnerships with a clear route to long-term sustainability within the life of the program. The **objectives** of the program are to (A) establish performance recording and sampling systems in Tanzania and Ethiopia; B) Use the information and samples collected to develop systems to select crossbred bulls and cows of superior genetic merit for artificial insemination (AI) and natural mating; C) Pilot farmer-feedback systems that assist farmers to improve their productivity and D) Establish public-private, non-government organizations, and producer partnerships necessary for funding and scaling the ADGG data capture system into a regional platform. The project covers the Oromia, Southern Nations and Nationalities and People (SNNP), Sidama, Amhara, and Tigray regional states and Addis Ababa city administration. In Ethiopia, ADGG is jointly working with the National Animal Genetics Improvement Institute (NAGII), the Ministry of Agriculture (MoA), regional bureaus of agriculture and livestock and several other domestic and international partners. ADGG responds to the above listed challenges that the Ethiopian dairy sector currently faces via innovative application of ICT tools and genomic technology through a harmonized national dairy cattle database and animal identification and registration system.

Experience: Approaches and achievements

Establishment of national database and data capture system

Genetic evaluation requires herds and animal data, captured accurately and consistently, and an organized national database with high-capacity servers and high security to maintain data. For timely and accurate data capture at reduced cost, the manual paper-based data capture system must be replaced with ICT tools that are more efficient but less expensive and ensures access to data online and offline.

Ethiopia dairy cattle database was officially established in 2012 under a joint project entitled "Capacity building in herd performance recording and genetic improvement to strengthen the Ethiopian dairy development" between the Finnish and Ethiopian Government. The project was financed by the Institutional Cooperation Instrument of the Ministry of Foreign Affairs of Finland and a substantial financial and in-kind contribution from the Ethiopian government. The implementation of the project was coordinated by Natural Resources Institute of Finland (Luke) in close cooperation with MoA and NAGII. The project built a computerized national dairy cattle database center and provided capacity building trainings for several experts and farmers. Towards the end of the Luke led pilot project the ADGG project was starting to implement its program on a wider scale and higher capacity.

The ADGG program supports Ethiopia's national dairy recording center [https://portal.adgg.ilri.org/] to routinely capture data digitally. It has established and continuously refines a digitalized online and offline data capture system to collect performance records of animals from the field. The offline data capture system is enabled using customized open data kit (ODK) collect forms. Moreover, systems for direct data collection from farmers via mobile apps and short messaging service (SMS) has been developed and is being fine-tuned and adapted for Ethiopia. These different avenues of data capture enumerated are supported by a robust and agile digital data platform, as illustrated in Figure 1.

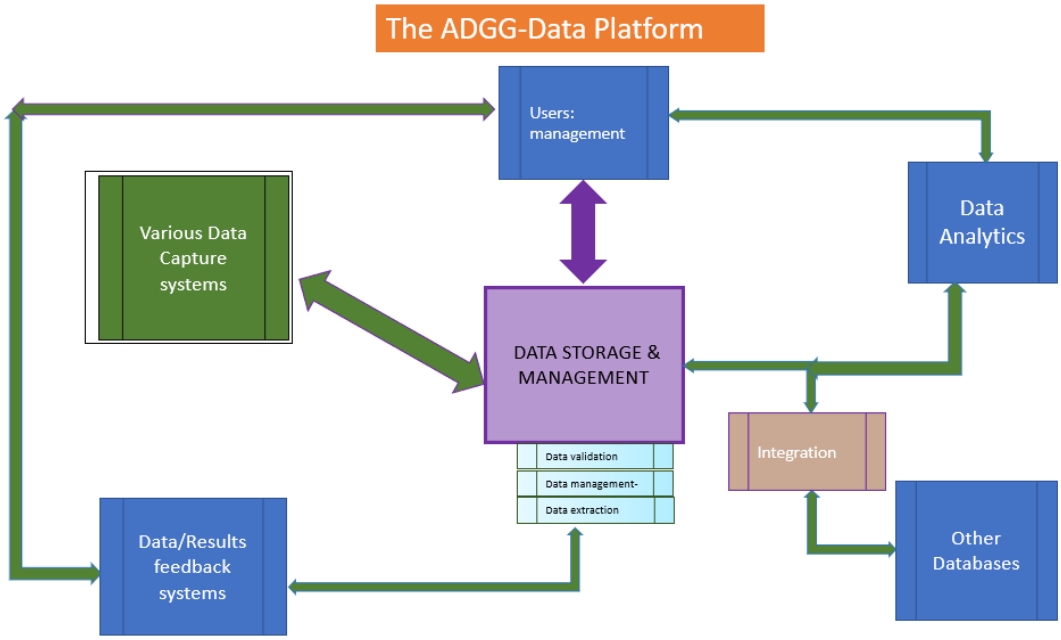

Figure 1: The schematic structure of ADGG data platform

National dairy animal identification

A national animal identification should be adopted as a system to support genetic improvement, control animal diseases and track animal movement, thus enable traceability of live animal and products. Currently, dairy cattle kept under research and private farms in Ethiopia are identified using ear tags which lacks uniformity and full of repeated numbers which makes it difficult to bring these data into one database. The ADGG platform has adopted a system of national animal identification and registration that was developed by NAGII and Luke, and if properly adopted, solves the problems associated with uniformity and repetition to register and monitor the performances of individual animals within a herd. In the naming nomenclature, the plastic ear tag consists of the national country code "ET" and nine-digit numbers with the last four digits printed in bold and bigger font just below the full identification code (see Figure 2). The numbering is designed to identify at least one billion animals if the system is promoted nationally, adopted and awareness created at different levels. To ensure sustainability of the system, The PAID project donated five ear tag printing machines, placed at NAGII, and at Bahir Dar, Nekemet, Hawassa and Mekelle AI centers. NAGII in collaboration with the regional livestock offices is authorized to control the printing, purchasing and distribution of the plastic ear tag and applicators across the country.

Figure 2: Plastic ear tag and identification number in Ethiopia

ICT for dairy data capture from farms

The rapid expansion of ICT alongside mobile based solutions for "paperless" exchange of information has catalyzed a transformation for information sharing in the smallholder farming systems of Africa (World Bank, 2011). The challenge within countries, Ethiopia included, is to adapt and expand critical infrastructure to support ICT adoption which includes mobile telecommunications networks and cloud computing facilities. ICT-enabled services can use multiple platforms (eg radio, e-tools, short message services) to provide information for various actors in the dairy value chain. Through the ADGG Program, mobile phone-based solutions have been adapted to capture and transmit data on performance of dairy cattle to the centralized national databases hosted on a cloud-based data platform (ADGG Data Platform). The ADGG data platform collates and synthesizes farm information and subjects it to various analyses using advanced analytical tools. Results from analyses are used to develop targeted feedback information that are then shared with farmers and extension service providers, to respectively inform their management and service delivery planning or decisions. Initial feedback information includes herd assessment, and individual animal and herd performance benchmarking. The platform has also developed electronic training resources that provide valuable information on breeding management practices in dairy herds (ADGG Dairy Tool).

Dairy herds and animals registered by ADGG, PAID and Luke projects have been harmonized into one national dairy cattle database. Total number of dairy herds, dairy cattle with pedigree and test-day milk records and test-day milk data registered in the digital ADGG platform are more than 72,000, 116,000 and 279,000, respectively. The data can be accessed via the Ethiopia

country landing page (see Figure 3). This program is piloted in 98 districts in Amhara, Oromia, SNNP, Sidama and Tigray regions and Addis Ababa city administration.

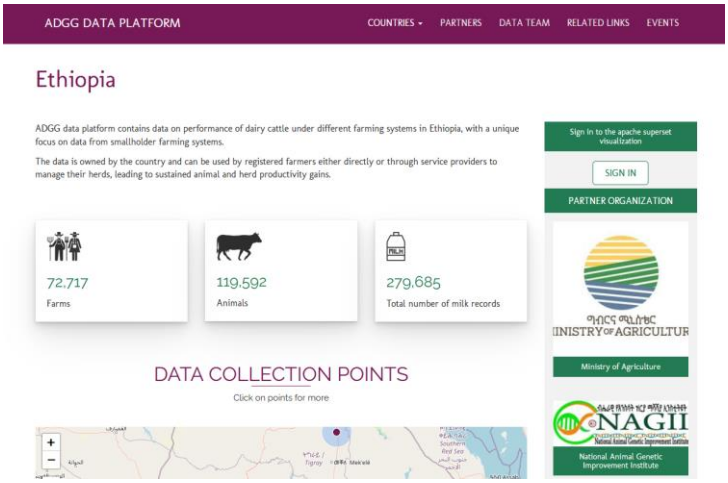

Figure 3: ADGG data platform landing page

ICT based extension and feedback

ICT based farmer-feedback systems have been developed and deployed to assist farmers improve their cows' productivity based on performance data collected from their herds. SMS based feedback system following the "cow's gestation calendar and dairy production management" support messages were reaching smallholder dairy farmers through digital extension. Farm data on milking and calving, AI service, feeding and other records, received from the farm through the ADGG platform is then synthesized and feedback shared with producers in the form of short text messages through their mobile phones. More than 8,890,258 education SMS messages and 162,456 instant feedback SMS messages based on cow gestation dates have been provided to farmers by ADGG in the last four years. The SMSs' have been translated into and delivered in three local languages (Amharic, Tigrigna and Afan Oromo). Information received by farmers guides their adoption of improved cow management practices which will ultimately lead to sustained productivity gains, income, nutrition, and poverty reduction.

Investors and service providers including cooperatives can also leverage on the platform's agility and robustness to better aggregate information on product quantities and demands for inputs in different areas. The public sector needs to have requisite policies in place that encourage innovation around ICT to enable the use of ICT services to promote improvements while at the

same time protect the smallholder producers from complex challenges when exposed to large global actors, and secure smallholders' ownership of data and appropriate data access rights. Appropriate, locally accessible, affordable, and smart tools and applications are required to inform timely decision making and to improve herd and system's productivity and profitability. Viability and sustainability of the dairy industry in sub-Saharan Africa, hinges on the integration of ICT tools that help increase accessibility of extension services by farmers. This is because of the highly fragmented nature of smallholder dairy herds, they can't all be reached by the public extension service and such limited access to extension services and support significantly hamper the sector's overall performance. Inadequate access to technical advice and services reduces the ability of farmers to address everyday challenges resulting in poor performance of the herd. Development and deployment of ICT based services would facilitate improvements in farm production and profitability, animal health, animal welfare, and the environment and at the same time create access to technical and market information that leads to improvement in efficiency and productivity gains along the dairy value chains (Mwantimwa, 2019). Moreover, the use of ICT holds considerable potential to make agriculture more attractive to the youth because of their receptiveness to ICT tools, making it easier for them to access dairy information and services (Nuer, 2018). Obstacles that hinder dairy farmers from accessing agricultural information using ICT tools include availability of electricity, internet connectivity and its ability to deliver timely agricultural information and feedback. Thus, advancement of policies and legislations by the government to enhance the adoption and use of ICT technologies in dairy farming are necessary to transform the dairy sector in the country.

Use of genomics technology for dairy genetic evaluation

Genomic selection has become the method of choice for identifying genetically superior sires and dams in developed countries due to the accelerated rate of genetic progress mostly because of the reduction in generation interval and increased prediction accuracy. In genomic selection animals can be selected accurately early in life, based on their genomic predictions. Furthermore, it is much more suited for selection of traits that are difficult or expensive to measure: such as fertility, disease resistance, methane emissions, and feed conversion traits (Hayes *et al*., 2013). Garcia-Ruiz *et al*. (2016) reported that genetic gains for milk, fat, and protein yields for registered cows in the USA were 50, 2.2, and 1.6 kg per year before genomic selection was

adopted but increased by over twofold to 109, 6.0, and 4.1 kg per year after genomic selection was introduced. The enabling factors for the huge success in genomic selection in developed countries include the availability of well-established infrastructure for routine data capture systems and conventional genetic evaluation. In addition, the existence of well-developed dairy breeding companies has significantly contributed to this success. These companies routinely undertake and/or contribute to the design of the genotyping strategy for widely used dairy bulls and the associated cost (Mrode *et al*., 2019). However, in developing countries, most of the dairy production occurs in small holder systems, where herd sizes are small and with little or no routine systems for capturing performance and pedigree data (Kosgey and Okeyo, 2007). The use of genomic information for genetic evaluation and determination of the breed composition of crossbred animal using admixture analysis (Strucken *et al*., 2017; Marshall *et al*., 2019), parentage identification and prediction of the genetic merit of animals using the genomic relationship matrix for genotyped animals present unique opportunities for mitigating the limiting data infrastructure in developing countries. In situations where only a proportion of the dairy cows are genotyped, the genotypic information can be combined with pedigree information using the Single Step GBLUP (ssGBLUP) approach (Misztal, *et al*., 2009) to undertake prediction of the genetic merit for all animals.

In Ethiopia, ADGG has applied genomic technology to genetically evaluate and determine breed composition of crossbred animals kept under small and medium dairy production system. Hair samples were collected from crossbred cows and bulls for genotyping. The samples were genotyped, and genotype information was combined with phenotypic data collected through the ADGG platform to estimate genomic estimated breeding value (gEBV) and thus select bulls and cows with higher genetic merit for breeding. The estimation of gEBV was based on a pilot data from 3,802 cows with 53,955 test day records and a pedigree consisting of 113,447 records. Genotypic data were available on 5,146 animals which were genotyped with the GeneSeek Genomic Profiler (GGP) Bovine 50K chip. About 47,843 single nucleotide polymorphisms (SNPs) were returned from the laboratory and after the usual edits, 40,581 SNPs were available for analysis. These were imputed to the Illumina HD chip (686,052 SNPs) using a reference population consisting of crossbred cattle from a previous East Africa Dairy Genetics Gain

project and several European Holstein-Friesian, Jersey, Guernsey, and Ayrshire purebred animals (Aliloo *et al*., 2018).

Initially, genetic parameters for milk yield were estimated from the same pilot data consisting of 3226 cows and 53147 test day records using ASReml (Gilmour *et al*, 2009) with ssGBLUP. For the parameter estimation, cows were required to have at least three test day records in a lactation, a minimum age at first calving of 18 months and days in milk was restricted to between 4 and 500 days. Data from all lactations were used but lactation greater than 1, were set to 2. The model fitted was:

Milk = HY + PYm + age.lac + fixed-lactation-curves(calving-season) + breed + htd + pe + animal

Where **HY**- herd-year of calving, **PYm** = production year-month, **htd** = herd-test-date, **age.lac** = age effects as interaction with lactation and fixed lactation curves consisted of Legendre polynomials and Wilmink function, **pe** and **animal** represents the permanent environment and additive animal genetic effect. The **H** matrix used in the ssGBLUP procedure consisted of 5169 animals with 4719 having only pedigree information and 450 of these with genotypes. The variances obtained from the model for the animal genetic, **pe**, **htd** and residual effects were 2.631, 4.264, 1.339 and 6.805 respectively and the heritability estimate was 0.17±0.03.

Similar edits applied for the estimation of genetic parameter were used for the genomic prediction except that cows with one test day records were included in the analysis. Thus 3802 cows with 53955 test day records were used for the genomic prediction. The genotypes on 5146 animals were included in the analysis, although only 609 of these cows also had test day records. All genotyped animals with no records were included in the genomic prediction analysis, so these animals can obtain predicted gEBV. The ssGBLUP procedure implemented therefore involved an H matrix consisting of 21724 animals with a weight of 5% on the A matrix in forming G_{22} matrix. The MiX99 software (Lidauer, *et al*. 2016) was used in the analysis to predict the gEBVs of animals and their reliabilities.

The animals were selected following the guideline developed by the ADGG project (https://portal.adgg.ilri.org/sites/default/files/ADGG_ETH_BULLCOW_sel_GUIDE_2020.pdf). The gEBVs of bulls ranged from -3.88 to 4.35Kg with a standard deviation of 0.84, implying that some of the top bulls available for selection are 4 to 5 standard deviations above the average bull, indicating that genetic progress can be made through using these the top bulls. Similarly, corresponding values for cows were -3.86 and 4.22 and 0.80 respectively. Top bulls and cows ranked on the estimates of gEBVs were made available for farmers.

Capacity building and awareness training

Building research and development infrastructure enables NAGII and regional livestock offices to effectively implement their genetic improvement plan. To this effect, the ADGG program equipped NAGII with high-capacity server (8 TB storage and 256 GB memory) to collect and store data. Besides, four Combo Lacto-Scan machines are procured to capture milk compositional traits and somatic cell count and each piloted district was provided with 100 motorbikes, 92 tablets, 15 laptops, printed plastic ear tags and heart girth measurement flexible tapes to enable smooth data collection and reporting and ensure uninterrupted monitoring of farms.

Work has also been done to strengthen the human and infrastructural capacity of the national system to collect field data, manage, analyze, and provide feedback to smallholder farmers. A total of 120 performance recoding agents (PRAs) are recruited and trained from 98 districts and large-scale farms from project regions on national dairy animal identification, importance of performance recording and data capturing using the ODK tool. PRAs visit dairy farms at least once a month, during which they advise the dairy farmer to whom they are assigned and capture new performance records. A critical component of the program, included, awareness creation, through trainings, which were organized and delivered to farmers, regional, zonal and district livestock office experts focused on merits of animals' identifications and keeping the history of individual animals to improve genetics, increase productivity and profit.

The capacity of 15 Ethiopian experts in quantitative genetics was enhanced through tailored training courses on data management, related statistical analyses, and hands-on genomic

breeding value predictions exercises. The data generated from the national herd performance recording system is being used for related research by five MSc and two PhD students' in writing their theses. Forty-five days full-fledged AI training was delivered to 15 PRAs in collaboration with the PAID project. AI kit and motorcycles were procured and distributed to all trained PRAs to ensure sustainability of data capturing and AI service provision to smallholder farmers.

First dairy cattle virtual parade

The first dairy cattle animal parade was held virtually on March 30, 2021, in the presence of dignitaries from the MoA, ILRI and BMGF and with the participation of senior government officials, farmers' representatives, researchers, development workers from domestic and international organization, private firms, research institute, and universities. The top ranked animals were exhibited and, six farmers (two out of the six are women), who owned three best bulls and cows were recognized and awarded. The purpose of the award is to motivate dairy farmers to participate in national animal identification, record keeping and genetic improvement activities actively and continuously. Further information on the first dairy animal parade event can be accessed from published articles in both hard copy and online using the following links: https://www.ilri.org/news/building-sustainable-livestock-genetics-improvement-system-food-secure-ethiopia and https://www.capitalethiopia.com/featured/ministry-of-agriculture-eyes-to-triple-dairy-production/

Dairy Animal Directory

The first dairy cattle directory in Ethiopia was also inaugurated by the Ministry of Agriculture on March 30th, 2021 and published online. The directory can be freely downloaded from the link below: https://hdl.handle.net/10568/113558.

Mobile application

Mobile based application has been developed and officially launched, the application has two modules, and presents top ranked animals, and artificial insemination center bulls with detailed information about the animals alongside pictures (see Figure 4). The list of top ranked animals will be continuously updated after all new national genetic evaluation results are released. The application is freely available to beneficiaries and service providers such as artificial insemination technicians. It helps in connecting seller and buyers of the top ranked animals,

whilst the list of bulls at AI centers will support farmers to select the bull breed type and exotic dairy breed composition best suited to their cows. The application can be downloaded using APK from " http://45.79.249.127/adggapi" link.

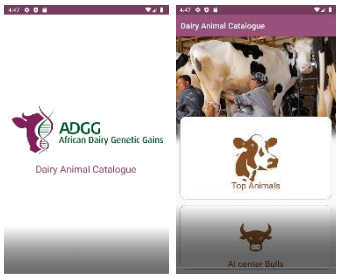

Figure 4: Mobile application for dairy animal mobile based catalogue, front pages

Animal certification

The first dairy animal certification system was based on the results from genomic based evaluation of the animals (see Figure 5). Farmers who own certified top ranked dairy animals are getting better price for their animals. Besides, cows and heifers with record builds confidence for both sellers and buyers of replacement animals. Provision of certificates to farmers increase trust and motivates them to continuously provide and send accurate data to the national dairy cattle platform. Soon dairy farmers will use their elite animals as collateral for loan arrangement from different financial institutions. Bulls certified through the genetic evaluation scheme could also be used for natural mating, replacing the unknown sires in communal grazing system.

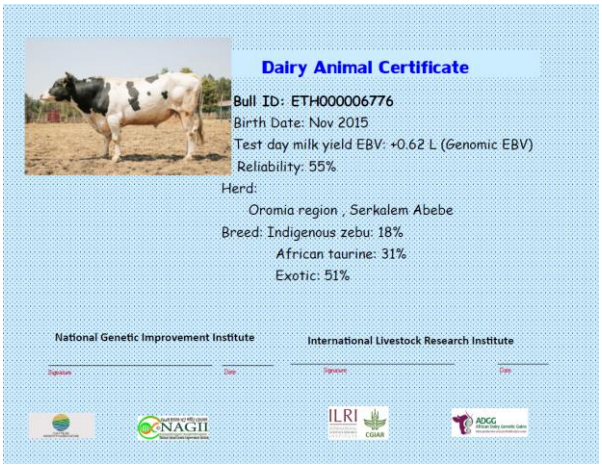

Figure 5. dairy animal certificate developed after the first-round of genetic evaluation

Partnerships

In Ethiopia, ADGG is working in collaboration with NAGII which represents the Ministry of Agriculture and many other domestic and international partners. Sustainable genetic improvement can be ensured through the participation of all stakeholders at various levels. To avoid duplication of efforts and ensure that partners complement each other for greater impact, institutions, the private sectors, non-Governmental organizations who are actively involved in Ethiopia dairy cattle research and development activities, have formed a partnership platform. The platform is working to harmonize animal identification, data collection and sharing or building sustainable genetic improvement program. Members of the platform are: NAGII, Agricultural transformation agency (ATA); Public artificial insemination delivery (PAID), Precision agriculture for development (PAD), Building rural income through inclusive dairy business growth in Ethiopia (BRIDGE), Project Mercy (PM), International Livestock Research Institute (ILRI), Green Dreams Technology (GDT) and Natural Resources Institute of Finland (Luke). Other potential institutions will be approached/invited to join the Ethiopia dairy cattle partnership platform for the betterment of dairy farmers in Ethiopia.

Prospects and challenges for scaling up and sustainability

Despite the huge livestock resources in the country, the benefits that the smallholder farmers get from their efforts, are currently relatively low. One challenge that contributes to the observed low productivity and profitability levels is limited access to productive but locally adaptable dairy genetics. The inputs and services required for genetic improvement and improved genetics delivery are inefficient with limited private sector participation. The ADGG project has laid a firm foundation for long term breeding program. Some of the cornerstones for the breeding program are the establishment of a harmonized national database, field data capture tools, pipeline for the analysis and selection of top-ranking sires and dams, genotyping strategy, and a digital system for sharing feedback and delivery of educational messages using ICT tools. Thus, it must be scaled up and sustained by engaging more farmers, the private sector, associations, and societies. The following are some of the suggested interventions for scaling up and sustainability.

Institutionalizing the breeding program: Sustainability of a breeding program requires ownership, commitment, and support by the government. The breeding program must be

institutionalized within NAGII and supported with resources to ensure the continuity of data capture, feedback, extension educational message, genetic analysis, selection of top ranked animals, promotion and use of top ranked bulls for semen production.

Engaging private sector: Private sector could play a pivotal role in designing and implementing a successful breed improvement programs and delivery of improved genetics. Government must support and encourage private sector to engage in long term business investment. Loan, land, property right and protection, etc. creates confidence to invest in breeding business in sustainable manner.

Continuous capacity building: Establishing a sustainable long-term breeding program requires continuous human and infrastructural capacity building. Domestic universities should play this role by designing or adjusting existing curriculum to produce skilled, well versed, and capable professiona1 in the field of animal breeding. Besides, linking graduate thesis and dissertations with ongoing activities will boost the data collection and facilitate execution of different trials or research within a specified period.

Farmers' continuous education: Creation of awareness to, and participation of farmers in good animal husbandry practices that relates to the ongoing breeding programs should be improved through continuous education. The system of educating farmers follow different modalities based on ease and access to infrastructure such as ICT, practical and theoretical trainings. Without feedbacks and continuous farmers education and using appropriate contents, long-term sustainable breeding programs might not be attractive for farmers to engage and participate in since the fruits of the whole process of data collection, genotyping and genetic evaluation are harvested after many years. Farmers' education methods currently being used including cellphone-based text messages, voice education messages, use of tablets for data capture, and videos should be scaled up for wider reach. Current data collection system uses PRA to collect data, upload and send to the central database. Such approach may not be a long-term solution to data collection. Farmer's education should also include aspects of data collection and sending using their mobile phone. This requires, continuous education on the importance of data capture and engaging farmers in participatory genetic evaluation.

Harmonized animal identification and registration system: Animal identification and registration are key to implementing sustainable genetic improvement, traceability of animals and animal products, disease control, management of animal movement and use of animals as collateral for loan acquisition. Identification and registration must therefore be scaled up and institutionalized within government structure. Short- and long-term government plans must include national animal identification and registration as one of the activities supported with budgets.

Building partnership among actors in the dairy value chain: Sustainable breeding program should be matched with improved feeding, health care, and access to quality inputs and services and market linkages to fully extract improved genetics and genetic gains. This way, national consumers, would be assured access to safer and more nutritious milk and milk products. Different initiatives targeting a specific node of the value chain should build partnership to complement their efforts and sustainably support the breed improvement programs.

Supportive government policies: Supportive government policies, regulations and guidelines needs to be formulated, enacted, and respectively availed to encourages the generation and wider application/uptake of new technologies and innovations related to improved breeds. This way, ownership, and property right and privileges to use the improved genetics at a wider scale would be ensured. To this end, policies that support establishment of breed societies aiming to improve specific breeds, benefit sharing, etc are needed.

Challenges for scaling up and sustainability

Project syndrome:

Project syndrome: Projects by nature are time-bound, with some being short lived and targeted to only demonstrate, generate, or design innovations. On the contrary, breeding program are long term, thus, scaling up, sustained implementation and demonstrated innovations needs long-term buy in from the government or private sector.

***Lack of ownership and long-term government commitment*:**
Long-term investments and lack of demonstrable immediate benefits or profit from breed improvement has not and may not attract policy makers attention and incentivize them to allocate adequate resources and make related investments. Thus, continuous dialogue with, and creation of awareness to the government is required.

Delay or limited private sector participation:
Private sector engagement in long term genetic improvement, improved genetics multiplication and delivery, and the provision of supportive services depends on the profitability of the business as well as government incentives and support. Thus, unless these are in place private sector participation could be limited at least in the short-term.

***Business competition for improved genetics delivery*:** Globally, the business of improved genetics is dominated by international companies, with many years of experience and reputation. Joining the improved genetics market for tropically adapted dairy breeds faces unique challenges, hence evidence needs to generate and packaged in ways that clearly demonstrate the relative competitiveness of such businesses before selling them the experienced companies. The ADGG program is trying to do that.

Conclusions
From the above review, the following conclusions can be made:

- Successful and sustainable breeding program depends on a functional national animal identification and registration system, phenotypic data recording, robust genotyping strategy, appropriate data analysis and estimation of genomic breeding values, proper selection indices, the basis on which ranking of bull and bull-dams and are done and finally the top genetics aggressively promoted and widely used through AI and natural mating to breed future cows.
- Farmer's participation will depend on the feedback and benefit they get by participating in the breeding program, thus periodic feedbacks and extension educational messages need to be shared with them for improved productivity and production. The accuracy of estimated genomic breeding values depends on the amount and quality of data and the size of the

reference population with both phenotypic and genotype information, thus, enhancing phenotypic data collection and increasing the number of animals genotyped improves the accuracy of the estimate.

- The success of a sustainable breeding program depends on the improved genetics delivery system and promoting the use of animals selected. Public and private service providers must use semen produced from elite bulls selected as top ranked animals. Elite bulls which are not used for semen production could be used for natural mating to replace indiscriminate uncontrolled natural mating.
- Sustainability of breeding programs depends on the degree participation of the private sector in the genetic improvement companies, breeder's society, professional societies or associations and in the delivery of improved genetics. Enabling environment must be designed by government to attract more private sector participation in such new business.

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