Developing livestock breeding strategies for enteric methane mitigation in developing countries – the case of Latin America

E.A. Navajas[1], J.M. Alvarez[2], S. Munilla[3,4], G. Ciappesoni[1], V.E. Vega-Murillo[5], R.J.C. Cantet[4], R. Calderón-Chagoya[6], M. Montaño-Bermúdez[6] and A. Berndt[7]

[1]Instituto Nacional de Investigación Agropecuaria, INIA Las Brujas, Ruta 48 km 10, 90200 Canelones, Uruguay
[2]Instituto Nacional de Tecnología Agropecuaria. Universidad Nacional de Río Negro - EEA Valle Inferior-UIISA Ruta nac. 3 km 971, camino 4, Idevi, Viedma 8500, Argentina
[3]Universidad de Buenos Aires, Facultad de Agronomía, 1417 Buenos Aires, Argentina
[4]Instituto de Investigaciones en Producción Animal, INPA CONICET, Buenos Aires, Argentina
[5]Facultad de Medicina Veterinaria y Zootecnia, Universidad Veracruzana, Veracruz, Ver, México
[6]Centro Nacional de Investigación Disciplinaria en Fisiología y Mejoramiento Animal, INIFAP, Querétaro, México
[7] Embrapa Southeast Livestock, São Carlos, SP, Brazil
Corresponding Author: enavajas@inia.org.uy

Abstract

Meat, dairy and wool industries are particularly important in Latin American (LA) countries given their significant contributions to national economies, generation of employment and rural development. Livestock industries are also relevant for ensuring food security in the region, and for the rest of the world attending the predicted increase in food demand of a growing global population. The LA region is responsible for 25% and 11% of the world beef and dairy production, respectively, with Argentina, Brazil, Mexico and Uruguay being among the major beef and dairy producing and exporting nations. Reducing enteric methane emissions (EME) is one of the challenges that the livestock industry faces in Latin America. Cattle and sheep are major sources of greenhouse gas (GHG) emissions in LA, particularly EME which represents from 11% (Mexico) to 42% (Uruguay) of the total GHG emissions in the considered countries. Animal breeding provides the opportunity to harmonise production growth and EME mitigations targets in the framework of the Paris Agreement and the Global Methane Pledge. The most important Bos taurus (Angus, Hereford, Holstein, Simmental, Charolais), Bos indicus (Nelore, Brahman and Guzerá) and composites (Brangus, Braford, Montana, Simbrah) breeds have genetic evaluation in place in Argentina, Brazil, Mexico and Uruguay, some of them established 30 years ago. Similarly, wool, dual purpose and meat sheep breeds are genetically evaluated in Argentina and Uruguay. Genetic evaluations systems include relevant traits related to production (reproduction, growth, carcass weight, milk production, fleece weight), and product quality (meat intramuscular fat, milk protein content, fibre diameter). Feed efficiency, assessed by residual feed intake (RFI), has been recently incorporated into beef cattle genetic evaluations in Argentina (Angus, Brangus, Braford), Brazil (Nellore, Guzera and Brahman) and Uruguay (Hereford). Genomic information has been integrated in many breeding programmes of cattle and sheep. This is particularly relevant for difficult to measure traits, such as RFI and EME, although expanding the reference population sizes for improving prediction accuracies remains a difficult task. EME phenotypes for breeding purposes are still scarce in the region. In 2021, Uruguay started recording

EME in Hereford, using GreenFeed units, during the RFI tests, and a similar approach will be implemented in Argentina in several breeds. An intensive phenotyping platform was developed in Uruguay for sheep, in which RFI and EME are measured. Based on data recorded with Portable Accumulation Chambers, the first genomic breeding values for EME have been published in Merino. The genetic evaluation system in these LA countries have been implemented based on associations between breed societies and academic institutions, including national research institutes and universities. These relevant and long-lasting collaborations between public and private sectors in Argentina, Brazil, Mexico, and Uruguay provide the basis for a coordinated regional programme for animal breeding strategies with the aim of mitigating EME and improving livestock performance. The critical step is implementing the phenotyping platform for EME for the main breeds. This implies improving EME recording in association with RFI and expanding it to grazing conditions. The first approach delivers key information to disentangle the links among feed intake, animal performance and EME. Data recorded in grazing animals allows investigating EME in the most relevant livestock production environment in the region, and potentially developing proxy measures for larger phenotyping carried out by breeders. Although feed intake, which is a main driver of EME, is a very difficult-to-measure trait, the information in the grazing system would provide valuable data for quantifying EME intensities and estimating EME factors. An integrated and collaborative approach among the mentioned countries would be able to provide breeding tools and information for breeders to contribute to current and future challenges, considering environmental, social, and economic sustainability.

Keywords: genomic selection, sustainability, greenhouse gas, residual feed intake, cattle, sheep.
Presented at the ICAR Anual Conference 2024 in Bled at the Session 8: Global challenges in genetic selection for lower methane emission in ruminants.

Introduction

Latin America (LA) is one of the main providers of meat and fibres of the world, comprising 30% and 6% of cattle and sheep stock in the world. The region has the largest reserve of land with agricultural potential determined by 16% of the world's agricultural land and 33% of its unused agricultural area. LA countries play a key role for food security not only in the region, but also for the rest of the world (OECD *et al*., 2023). Reinforcing the path towards a more sustainable livestock production is relevant for the region to face current and future challenges, given that food consumption is expected to increase by 1.4% per year in the next decade due to the population growth. Estimates indicate that for the next decade a global growth of beef production of 8%, with LA accounting for 33% of this growth and reinforcing its position as world primer exporter of agricultural products such as beef (OECD-FAO, 2022).

Most of the greenhouse gas (GHG) emissions in LA countries are from the agricultural sector accounting for 40% of total emissions (CO2 eq)(Cárdenas and Orozco, 2022). In particular, enteric methane emissions (EME) from ruminants explain between 6 and 43%, proportion explained by combined effect of the relevance of the livestock sector and relative magnitude of other economic sectors, such as the energy sector (Tedeschi *et al*., 2022). These figures highlight the significant impact of reducing EME on total GHG emissions and, at the same time the importance of implementing EME mitigations strategies in the livestock industry.

Addressing EME strategies in LA must take into account the economic, social and environmental relevance of livestock production, and drastic alternatives, such as reducing national flocks and herds to decrease total EME would have significant unfavourable implications in all dimensions defining sustainability. LA is integrated by developing countries where livestock production is economically very relevant and a key activity for rural development and source of employment globally in the livestock industry. Additionally, it is important to mention that livestock farming is also related to other characteristics associated with the environmental dimension of sustainability, as an important proportion of cattle and sheep are raised in grazing conditions, with an important proportion of natural grasslands (OECD-FAO, 2022). Carbon sequestration by soil and biodiversity conservation (i.e. Duarte-Guardia *et al*., 2024) are examples of aspects related to GHG mitigation and environmental sustainability in the livestock production systems.

Animal selection offers the opportunity to harmonise production growth and EME mitigations targets in the framework of the Paris Agreement and the Global Methane Pledge, subscribed by LA countries. This work focuses on four main beef and sheep producers and exporters countries in LA: Argentina, Brazil, Mexico and Uruguay. The genetic evaluations systems in place in these countries provide the basis for the assessment of the impact of animal breeding on EME and the integration of EME phenotyping. It will help investigate alternatives to accelerate genetic selection for lower EME while reconciling all sustainability dimensions. In this article we describe the contribution of these countries to the EME in the region and relevance as livestock producers, their current breeding programmes and how the integration of EME phenotyping can contribute to reduce EME and achieve mitigation targets.

Livestock production and GHG mitigation targets

Cattle and sheep stock in Argentina, Brasil, Mexico and Uruguay represent more than 75% and 65% of the total in LA for each species, respectively. Livestock production explains a proportion of the national gross domestic product (GDP) that varies between 28 to 43% (Arango *et al*., 2020), being among the major beef producing and exporting nations.. In all cases, the agricultural sector (agriculture, forestry and other land use sector in the national GHG inventories, AFOLU) is responsible for significant proportion of total GHG emissions, and EME represents a high proportion of the AFOLU GHG emissions (Ruden *et al*., 2023).

Global national mitigations targets have been defined in all countries, in accordance with the Paris Agreement, in terms of emission intensity and total emissions. For 2025, total reductions in GHG intensities of 25% and 50% have been proposed by Mexico and Uruguay, respectively. For 2030 specific mitigation targets in absolute terms for each GHG have been defined in Uruguay, as well as a specific goal of lowering by 35% the EME intensity in the cattle sector. Argentina committed to a reduction of total GHG emissions of 27,7%, without a reduction in livestock stocks, this implies lowering EME intensities by increasing efficiency. México committed to an unconditional reduction

Table 1. Livestock production and enteric methane emissions by country.

	Argentina	Brazil	Mexico	Uruguay
Economic characterization [1]				
Cattle numbers (million heads)	53.9	214	33.5	11.3
Area (million ha)	110	168	197	13.3
Contribution to national GDP (%)	3	6.8	1.6	6
Contribution to agricultural GDP (%)	38	30	43	28
GHG emissions profile [2,3]				
AFOLU contribution to total GHG (%)	45.0	48.5	19.0	75.4
Contribution of EME to AFOLU (%)	33.3	45.6	78.3	57.5

[1]Adapted from Arango et al. (2020);
[2]Adapted from Ruden et al. (2023);
[3]Adapted from MAyDS (2023)

of 25% of its GHG and Short-Lived Climate Pollutant (SLCP) emissions by 2030. This commitment implies a 22% reduction of GHGs and a 51% reduction of Black Carbon.

Genetic evaluations in cattle and sheep

Cattle and sheep national genetics evaluations have been in place South America since late-80´s (Mueller *et al*., 2016; Navajas and Baldi, 2016; Ravagnolo *et al*., 2023) and established in Mexico in the early 2000s (Ríos Utrera *et al*., 2021).The genetic improvement programs in both species have been implemented through collaborative development among academic institutions and breed societies. The main cattle and sheep breeds are generically evaluated, and as described in Table 2. The most important Bos taurus, Bos indicus and synthetic Taurus x Indicus breeds are considered in the genetic evaluations systems, as well as the most important wool, dual purpose and meat sheep breeds.

Main production traits in beef cattle and sheep genetic evaluation

A comprehensive set of traits directly related to reproductive performance, growth and carcass and meat quality are considered overall in beef cattle in the different countries, as reported by Navajas and Baldi (2016). More detailed description of specific traits can be found at FAGB (2023) for Argentina, Pampaplus (2023) and Embrapa-Geneplus (2024) for Brazil, Ríos Utrera *et al*. (2021) for Mexico, and Ravagnolo *et al*. (2023) for Uruguay. Across countries and beef cattle breeds, there is a prevalence of growth traits such as birth weight, weaning weight, milk production and final weight (recorded at 15/18 months of age).

A second group of traits considered in the genetic evaluation systems are indicator traits of carcass and meat quality composition, which are measured by ultrasound: eye muscle areas, subcutaneous fat depth and intramuscular fat. Regarding reproductive performance, scrotal circumference is the most common trait seen in the genetic evaluations, as well as mature cow weight and calving ease, although other specific reproductive traits are present in the genetic evaluations (gestation length, age at first

Table 2. Genetic evaluations: main beef cattle and sheep breeds by country..

Cattle and sheep breeds	Argentina	Brazil	Mexico	Uruguay
Cattle				
Angus	X	X	X	X
Hereford	X	X		X
Limousin	X		X	X
Brahman	X	X	X	
Nellore		X		
Simmental			X	
Simbrah			X	
Charolais			X	
Brangus	X	X	X	
Braford	X		X	X
Sheep				
Australian Merino	X			X
Dohne Merino	X			X
Corriedale	X			X
Texel	X			X

calving, etc). A similar situation is observed at sheep genetic evaluations in which wool production and quality are very relevant, in addition to growth and reproductive traits (Álvarez *et al*., 2014; Ravagnolo *et al*.,2023).

Inclusion of feed efficiency

Feed efficiency is a new trait included in the genetic evaluation of beef cattle. Residual feed intake (RFI), defined as the difference between actual and predicted feed intake (Koch *et al*., 1963), implies reducing feed intake without compromising animal performance. Consequently, improving feed efficiency by selecting for RFI is an appealing new breeding objective because it leads to improved net income by reducing feed costs without affecting economic income. At a production system or national level, improving RFI could also be interpreted as a contribution to optimise the use of limiting resources, such as land in pasture-based production systems (Navajas *et al*., 2022).

Feed efficiency tests to assess RFI are performed in the four countries. In Argentina, INTA has five RFI phenotyping stations placed in the most relevant livestock production areas and other private facilities are recording RFI (Pordomingo, 2022). A public-private partnership between INTA, the University of Buenos Aires, Breeders Associations and private organisations is responsible for the evaluation of bulls of many breeds, such as Angus, Brangus, Braford and Hereford. Because RFI recording recently started the number of evaluated animals is still limited, but rapidly increasing and the EBVs are being published by the breeder societies. Argentina also started to register RFI in Merino and Dohne Merino at INTA Chubut Experimental Station and another facility is planned in southern Patagonia, which will also include Corriedale.

Several initiatives are in place in Brazil for measuring RFI in Bos taurus and Bos indicus and composites. For example, Embrapa Beef Cattle Unit has had a continuous private-public partnership with the company Geneplus Consulting Ltd, giving rise to the Embrapa Geneplus Program that involves 10 beef cattle breeds. In Nellore, since 2021, EPDs for RFI have been released for all breeders. Vast research has been carried out in the Canchim breed by Embrapa Southeast Livestock, where RFI measurements take place in this breed. a. Furthermore, in the Embrapa Southern Livestock Unit, the beef cattle breeding and research team has collected RFI data in Angus, Brangus, Hereford, Bradford and Charolais breeds, an initiative implemented in partnership with the breeders associations.

Similarly, initial tests for RFI have been conducted in Mexico since 2019 in collaboration with the Mexican Simmental and Simbrah Cattle Association, using the GrowSafe system. In Uruguay, RFI is in the Hereford genetic evaluation based on the information recorded in the post-weaning feed efficiency tests of Hereford bulls and steers, carried out at the e Central de Prueba Kiyú of the Hereford Breeders Society of Uruguay (Pravia *et al*., 2022). More recently, RFI at finishing (feedlot) is also evaluated in steers immediately after the post-weaning test, although this trait is not included in the genetic evaluation (Navajas *et al*., 2022). In the case of sheep, Australian Merino has the first estimations of genetic merit for RFI, although RFI information is being collected at INIA Experimental Station La Magnolia where lambs of the main wool, dual purpose and meat sheep breeds of Uruguay have been measured post-weaning since 2018: Australian Merino, Corriedale, Dohne Merino, Merilin and Texel lambs. Animals evaluated here belong to Selection Nucleus (Australian Merino), Information Nucleus (Corriedale, Dohne Merino, Texel) and commercial stud-flocks (all breeds) and are strongly connected with populations in the genetic evaluation (performance recorded) (Navajas *et al*., 2022).

Implementation of genomic selection

In the last decade, several of the cattle breeding programs have implemented genomic selection. This represents an important step for accelerating genetic progress by enhancing prediction accuracies at an earlier age. Additionally, it facilitates the inclusion of hard-to-measure traits, such as feed efficiency and EME, which can be improved more effectively.

Brangus and Braford breeds in Argentina have recently implemented genomic evaluations in collaboration with the Animal Breeding Group of the University of Buenos Aires, based on the methodology by Cantet *et al*. (2022). Argentinian Angus also implemented the genomic evaluation a few years ago, which was carried out by INTA (Instituto Nacional de Tecnología Agropecuaria) (Curutchet *et al*., 2023). In the case of the Hereford breed in Argentina, as well as in Uruguay, genomic evaluation was available in the context of the Pan-American Hereford Evaluation that included genotypes of all countries in the reference population (Navajas and Baldi, 2016).

Embrapa has implemented genomic evaluations in several breeds in partnership with different organisations. For example, in association with ABCZ (Brazilian Zebu Breeders Association), Embrapa Geneplus Program is responsible for the biggest Nellore genomic evaluation in the world (13 million animals, 306k genotypes). In the south, Embrapa Southern Livestock in collaboration with three animal genetic improvement programs (Pampaplus, Promebo and Brangus+) has contributed to the implementation of genomic selection in Angus, Hereford, Braford and Brangus.

In Mexico, genomic data has been included in genetic evaluation in Simmental and Simbrah breeds. In 2016 the first genomic evaluation was made, with the support of genetic improvement researchers from the National Institute of Forestry, Agriculture and Livestock Research (INIFAP), establishing a strategic alliance to develop the procedure for estimating direct genomic values in the Mexican Simmental and Simbrah cattle population. There is a reference population of 1,250 Simmental and Simbrah animals, selected on the basis of their marginal genetic contribution in the population and with EPDs for all traits included in the Genetic Evaluation, in particular for growth traits, frame score, scrotal circumference and stayability. On the other hand, activities have been carried out to integrate reference populations for feed efficiency and carcass characteristics measured by ultrasound. Once the appropriate number of animals with phenotypic information is available, genotypic characterisation will proceed with a high density microarray and the development of equations to predict genomic values for RFI, marbling, and ribeye area.

Genomic data has been included in the genetic evaluations in Angus and Hereford breeds in Uruguay that lead to the publication of genomic breeding values since 2016 and 2021, respectively (Ravagnolo *et al*., 2023). In the case of RFI, an initial binational reference population comprising 731 Uruguayan and 1168 Canadian Hereford bulls and steers was the basis for estimating genomic expected progeny differences (GEPD), which have been published since 2017. The assessment of prediction ability using two validation strategies concluded that it is possible to predict accurate and unbiased RFI GEPDs for non phenotyped selection candidates based on genomic prediction (Pravia *et al*., 2023).

Incorporation of methane emissions in genetic evaluations

Several studies confirm that EME is a heritable trait (cattle, range 0.10-0.45, Dressler *et al*. 2024); sheep, range 0.17-0.34, Jakobsen *et al*., 2022, Marques *et al*., 2022), confirming that selective breeding can support the reduction of EME. To make this possible, phenotyping EME is required in a large number of animals to be able to obtain accurate estimations of genetic correlations between EME and production traits. Having in mind that EME is a difficult-to-measure trait, genomic selection will have an important impact and a large reference population needs to be built. Recording EME is the first main challenge for implementing genetic selection for lowering EME. Although different methods to measure are available, all have advantages and limitations in terms of accuracy, ease of use and setting in which they can be used (Tedeschi *et al*., 2022). In LA, several of these methods are being used with a variety of purposes.

Respiration chambers are the gold standard method, and four units are available at INTA in Balcarce and Leales Experimental Stations (Argentina) and four at Embrapa Dairy Cattle (Brazil). Expertise regarding the use of SF6 is available in the region and the method has been used extensively for the evaluation of other mitigation interventions such as forage quality, finishing systems (grazing vs feedlot) and different pasture-based systems (Loza *et al*., 2024). However, for measuring EME in association with feed efficiency tests and expanding it for grazing conditions and massive data recording, GreenFeed and Sniffers are the preferred options for cattle and Portable Accumulation Chambers (PAC) for sheep.

Methane emission and feed efficiency

The first EME measurements using GreenFeed units in South America were at Embrapa Southeast Livestock. In 2014 and 2015, animals from different lineages of the Canchim breed were monitored for EME, both on pasture and in confinement, as well as in relation to feed efficiency in confinement (Méo-Filho *et al*., 2020). In Uruguay, EMEs started being recorded during the post-weaning RFI tests in Hereford using GreenFeed units, as well as during the finishing RFI evaluations. Similarly, new GreenFeed units have been installed in feed efficiency facilities at INTA for the evaluation of Angus, Hereford, Braford and Brangus located in several INTA experimental stations in different regions in the country (Anguil, Rafaela, Mercedes, Valle Inferior, Cesáreo Naredo).

The EMEs in Mexico have been measured using Sniffers, which operate based on the methodology developed by Garnsworthy *et al*. (2012), involving continuous analysis of gas concentrations using an infrared methane analyzer. This system utilises the Guardian NG - Infrared Gas Monitor to retrieve concentration data of gases second by second in the ambient environment. Before implementation, the equipment underwent calibration using methane gas at known concentrations, and were then installed in modified feeders to establish a closed environment, thereby mitigating external influences on measurements.

Incorporating EME measures to the feed efficiency test in both cattle and sheep provide very valuable information, particularly considering that animals recorded are part or linked to the populations in the genetic evaluations. In addition to the possibility of estimating genetic parameters for EME, the combination of feed intake and animal performance data allows to disentangle the associations between them and EME. This is very relevant for understanding the impact of genetic selection on the three EME metrics:

1. absolute EME measured in the animal,
2. EME intensity express emissions relative to livestock production (g/kg meat, milk or wool produced), and
3. EME yield, which is the ratio between absolute emissions and the feed intake expressed as dry matter intake (g/kgDMI) (Beauchemin *et al*., 2022).

Additionally, quantifying the role and impact of RFI as indirect selection criteria for reduced EME would be possible in different breeds.

Measuring methane emission in grazing conditions

EME in grazing conditions is a particularly important and challenging step that needs to be considered, given the relevance of pasture-based livestock farming in the region. In this context the use of GreenFeed units provides a feasible alternative for EME recording. Focusing these measurements on animals also linked to the genetic evaluations will be beneficial. Given the limited experience and the technical demands of continuous use of the equipment a first step would be to implement EME recording in experimental stations, before designing the expansion to commercial settings such as breeder and stud farms.

In Uruguay, two Hereford herds (INIA Glencoe and INIA Las Brujas) and the Central de Prueba Kiyú where feed efficiency and EME are measured in bulls and steers constitute the Hereford information nucleus. Sires selected by genetic merit for feed efficiency are used in both herds, which also provide steers for the feed efficiency test at finishing that are evaluated for carcass and meat quality traits. Growth and reproductive performance in grazing conditions are recorded in the herds. Therefore, the inclusion of EME recording in the herds will complement the information measured at the feed efficiency tests.

Other challenges

Beyond the expected significant impact of genetic selection on EME mitigation, it is a slow process. This emphasises the need of implementing not only phenotyping platforms for EME recording associated with genetic evaluations to accelerate genetic progress but also addressing other challenges to promote the adoption of genetic tools by breeders and encourage finance support by policy makers and funding bodies. Examples of these challenges include quantification of impact of genetic selection at farm and regional levels, developing linkages with GHG inventories to be able to report mitigation impact by animal breeding, reinforcing knowledge transfer programs and promoting breeders' engagement in this process and implementing direct or indirect economic incentives for farmers to select for this trait.

Genetic evaluations systems of the four countries considered here are carried out by or with the support of their national research institutes and universities, in strong partnership with the private sector. Additionally, national research institutes have direct links with national government agencies and regional forums and initiatives. This provides a valuable opportunity for the development of effective communication strategies with key stakeholders of the private and public sectors.

Conclusions

The LA region has genetic evaluations systems in place in the main livestock producers and exporters countries, with the capabilities to incorporate EME platforms that would enable accelerating genetic progress to reduce EME and achieve the GHG mitigation targets. An integrated and collaborative approach among Argentina, Brazil, Mexico and Uruguay will facilitate providing breeders and farmers with genetic tools for current and future challenges, considering environmental, social, and economic sustainability. In direct connection with policy makers and regional forums, effective communication strategies could be implemented to position animal breeding as a major contributor to improve livestock productivity and reduce EME in the region.

List of references

Álvarez, J.M., Mueller, J.P., Vozzi, P.A. and F. Milicevic. 2014. Objetivos de mejoramiento e índices de selección para la raza Corriedale en Argentina. Memorias XV Congreso Mundial Corriedale: 19 -33.

Arango, J., Ruden, A., Martinez-Baron, D., Loboguerrero, A.M., Berndt, A., Chacón, *et. al*., 2020. Ambition Meets Reality: Achieving GHG Emission Reduction Targets in the Livestock Sector of Latin America. Front. Sustain. Food Syst. 4:65.

Beauchemin, K.A., Ungerfeld, E.M., Abdalla, A.L., Alvarez, C., Arndt, C., Becquet, P, *et al***.,** 2022. Invited review: Current enteric methane mitigation options. J. Dairy Sci. 105:9297–326.

Cantet, R.J.C., Angarita-Barajas, B.K., Forneris, N.S. and S. Munilla, 2022. Causal inference for the covariance between breeding values under identity disequilibrium. Genet Sel Evol 54.

Cárdenas, M. and Orozco, S. 2022. The challenges of climate mitigation in Latin America and the Caribbean: Some proposals for action. UNDP LAC PDS Nº. 40.

Curutchet, A.R., Fragomeni, B.O., Guitou, H. and A. Monti, 2023. Exploring Alternative Approaches for the National Argentine Angus Cattle Genomic Evaluation Program. J Anim Sci 101: 38–39.

Dressler, E.A., Bormann, J.M., Weaber, R.L. and M.M. Rolf, 2024. Use of methane production data for genetic prediction in beef cattle: A review. Transl Anim Sci. 8:txae014.

Duarte-Guardia, S., Peri, P.L., Martinez-Pastur, G., Lasagno, R., Lencinas, M.V., Thomas, E., and B. Ladd 2024. Value of Biodiversity on Patagonian Rangeland: Estimation via a Hedonic Price Index. Rangeland Ecology and Management 92: 122–128

Embrapa-Genplus (2024). Sumario de Touros. https://geneplus.com.br/

FAGB, 2023. Guía de Procedimientos Sugeridos (GPS) para la Evaluación Genética de Bovinos de Carne. Foro Argentino de Genética Bovina.

Garnsworthy, P.C., Craigon, J., Hernandez-Medrano, J.H. and N. Saunders, 2012. On-farm methane measurements during milking correlate with total methane production by individual dairy cows. J. Dairy Sci. 95: 3166–80.

Jakobsen, J.H., Blichfeldt, T., Linneflaatten, L., Gløersen, M.O., Wallin, L.E. and J.C. McEwan 2022. Methane emission has low genetic correlations to lamb growth traits in Norwegian White sheep. Proc. of 12th World Congress on Genetics Applied to Livestock Production

Koch, R.M.,, Swiger, L.A.,, Chambers, D., and K.E. Gregory, 1963. Efficiency of Feed Use in Beef Cattle. J Anim Sci. 22:486–94.

Loza, C., Cerón-Cuchi, M.E., Cabezas-García, E.H.,, Ortiz-Churra, A., Gualdrón-Duarte, L. and J. Gere, 2024. On the use of SF6 gas tracer technique in Latin America for measuring methane emissions in ruminants: a review and analysis. New Zeal J Agr Res: 1-30

MAyDS. 2023. Quinto Informe Bienal de Actualización de Argentina a la Convención Marco de las Naciones Unidas sobre el Cambio Climático (CMNUCC).

Marques, C.B., De Barbieri, I., Velazco, J., Navajas, E.A. and Ciappesoni. G. 2022. Genetic parameters for feed efficiency, gas emissions, oxygen consumption and wool traits in Australian Merino. Proc. of 12th World Congress on Genetics Applied to Livestock Production

Mueller, J., Vozzi, P.A, Giovannini, N. and J.M. Álvarez 2016. Beneficio del progreso genético en ovinos de la Argentina. RIA 42: 307 - 316.

Navajas, E.and F. Baldi, 2016. Beef cattle genetic evaluations in South America. In: ICAR Chile - Interbeef Meeting Puerto Varas, Chile.

Navajas, E.A., Ravagnolo, O., De Barbieri, I., Pravia, M.I., Aguilar, I., Lema, M.O., *et al.* 2022. Genetic selection of feed effi-ciency and methane emissions in sheep and cattle in Uruguay: progress and limitations.Proc. of 12th World Congress on Genetics Applied to Livestock Production. 164–7.

OECD *et al*., 2023. Latin American Economic Outlook 2023: Investing in Sustainable Development, OECD Publishing, Paris.

OECD/FAO, 2022. OECD-FAO Agricultural Outlook 2022-2031, OECD Publishing, Paris,

Pampaplus 2023. PAMPAPLUS: sumário de avaliação genética Hereford e Braford 2023.

Pordomingo, A. 2022. Residual feed intake: un indicador de eficiencia que se instala en la ganadería bovina argentina. IDIA 21 2 (1) : 28-35.

Pravia, M.I, Navajas, E,; Aguilar, I. and O. Ravagnolo, 2022. Evaluation of feed efficiency traits in different Hereford populations and their effect on variance component estimation. An Prod Sci 62: 1652-1660.

Pravia, M.I, Navajas, E,; Aguilar, I. and O. Ravagnolo, 2023. Prediction ability of an alternative multi-trait genomic evalua-tion for residual feed intake. J Anim Breed Genet 140:508–18.

Ravagnolo, O., Aguilar, I., Ciappesoni, G. and E.A. Navajas, 2023. Investigación y aplicación de la mejora genética animal para una producción ganadera más sostenible. In: Aportes científicos y tecnológicos del INIA del Uruguay a las trayectorias agroecológicas. p. 373–94.

Ríos-Utrera, A., Martínez Velázquez, G., Calderón Chagoya, R., Montaño Bermúdez, M. and V.E. Vega Murillo, 2021. Beef cattle genetic improvement research at the INIFAP: accomplishments, challenges and perspective. Rev. mex. de cienc. pecuarias 12:1-22.

Ruden, A., Torres, F., Berndt, A., Gómez, C., Salazar, F., Casallas, I., *et al.*, 2023. Status and opportunities for improvement in greenhouse gas emission inventories for the cattle production in Latin America and the Caribbean region: A perspective. PLOS Clim 2: e0000101.

Tedeschi, L.O., Abdalla, A.L., Álvarez, C., Anuga, S.W., Arango, J., Beauchemin, K.A., *et al*., 2022. Quantification of methane emitted by ruminants: a review of methods. J Anim Sci 100:skac197