https://doi.org/10.32854/agrop.v13i10.1712

Dietary alternatives in livestock production for mitigation of greenhouse gas emissions in Mexico

García-Piña, Elizabeth Y.[1]; Herrera-Torres, Esperanza[2]; Murillo-Ortiz, Manuel[1]; Reyes-Jáquez, Damián[3]; Carrete-Carreón, Francisco O.[1]; Pámanes-Carrasco, Gerardo A.[4]

[1]Universidad Juárez del Estado de Durango, Durango, Dgo., México. C.P. 34000. [2]Instituto Tecnológico del Valle del Guadiana, Durango, Dgo., México. C.P. 34371. [3]Instituto Tecnológico de Durango, Durango, Dgo., México. C.P. 34080. [4]CONACyT-Universidad Juárez del Estado de Durango, Durango, Dgo., México. C.P. 34000.

***Corresponding author**: gerardo.pamanes@gmail.com

ABSTRACT

Objective: To analyze the alternative sources of food for livestock production to mitigate greenhouse gas emissions in Mexico.

Design/methodology/approach: A document archive analysis was carried out about the use of certain industrial and agricultural wastes in Mexico in the last decade, and how these can serve as an alternative source of animal feed; these offer certain chemical properties that promote the mitigation of greenhouse gas emissions in livestock systems and also generate an added value in the agricultural and industrial sector.

Results: Agricultural and industrial production in Mexico generates an important amount of wastes that are not exploited; in parallel, livestock production in Mexico is growing exponentially, which demands a surface and consumption of natural resources. Therefore, agricultural and industrial residues in Mexico represent a potential alternative source of animal feed, which offers a reduction in the surface destined to the production of food for animals and gives an added value to the industrial and agricultural residues in the country.

Study limitations/implications: The alternative sources of food adjust to the agricultural and industrial sectors.

Findings/conclusions: The use of agricultural residues, industrial wastes, and other alternate sources of food is suggested as a sustainable alternative in the reduction of GHG in livestock systems and a contribution to the mitigation of climate change in Mexico.

Keywords: ruminants, alternative sources of fodder, methane, ruminal fermentation.

INTRODUCTION

It is estimated that by the year 2050, the Earth's population will be approximately 9 billion (FAO, 2017). This promotes an increase in the livestock sector to supply the dietary needs of the population (Ramírez-Ramírez, 2016). This increase in the production implies an increase in the use of natural resources and spaces, which is why its optimization ought to be contemplated.

Agroproductividad: *Vol. 13, Núm. 10, octubre. 2020. pp: 75-81.*
Recibido: *junio, 2020.* **Aceptado:** *septiembre, 2020.*

Imagen de Alexas_Fotos en Pixabay

The disposition of natural resources has been affected by climate change, mainly because of the increase in greenhouse gases (GHG) whose origin is anthropogenic. The main gases associated to this effect are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (NO_2) (Martínez-Prado, 2016).

Ruminants contribute with 53% of the total anthropogenic emissions of CH_4 (Hernández-Medrano, 2018). Methane is synthesized as a product of anaerobic ruminal fermentation, and its synthesis represents a loss of energy for animals, which is quantified in up to 12% (Vélez *et al*., 2014). In addition, the caloric power of CH_4 is 21 times higher than CO_2 (Valencia-Trujillo & Rojas-López, 2019). In Mexico, the agriculture and livestock activity contributes with close to 71% of the total emissions of CH_4 (Saynes-Santillán *et al*., 2016). In this sense, the farming sector covers 73% of the national territory. The economic activity of livestock production has a population of 33.8 million bovines and represents 3.8% of the national GDP (SIAP, 2018). Therefore, sustainable alternatives are sought that can serve as feed for livestock, and which in addition can cover the basic nutritional requirements of the animal, established by the National Research Council (White *et al*., 2017). Additionally, it is hoped that the alternative sources suggested do not represent a direct competition in the use of resources for human consumption and, at the same time, can reduce GHG emissions through modifications in the diet that ensure changes in ruminal anaerobic fermentation (Buitrago-Guillén *et al*., 2018). As a result of this, diverse methods and systems have been proposed, as well as alternative food sources that contribute to the mitigation of GHG in livestock systems, which are already in use or can be applied in Mexico. Based on this, alternative sources of food for livestock production were analyzed with regard to mitigation of greenhouse gas emissions in Mexico.

Silvopasture systems

Livestock production in Mexico is carried out by different systems: intensive, extensive and mixed. In the first, producing animals are stabled in an area that does not constitute the land where their main sources of food are sown, so they depend on being supplied with feed, energy and other necessary inputs for livestock production; in the second, the producing animals are kept in large land extensions and are fed mainly on seasonal grasses and fodders, with which they are in constant contact; meanwhile, in the third type of exploitation, the crops of animal and human food sources and the productive animals, are in constant contact. This last system produces more than 50% of total meat production and more than 90% of the total milk production in the world (FAO, 2014a). In fact, the silvopasture system is included among mixed production systems. The silvopasture system (SPS) is one where forestry, agricultural and livestock production activities are combined, and which also contributes to mitigate the effects of climate change (Arciniega-Torres and Flores-Delgado, 2018).

SPSs can be systematic (as live fences, pastures, passages, etc.) or non-systematic (disperse in pasturelands or grazing) with broad forest density (Buitrago-Guillén *et al*., 2018; Cisneros, 2019). The types of trees that can be included in this system are varied, since they can be native species or else introduced.

In this sense, the species selected for the SPS are distributed in a way that they take advantage of the characteristics of the land, obtaining benefits in the sectors implicated, such as the livestock contention fences and the exploitable forest volume, which improves water retention in the soil and decreases erosion (Canizales-Velázquez *et al*., 2019). This allows for a regeneration of nutrients and microorganisms in the soil, in addition to regulating the temperature in the zone (Villanueva, 2018).

Authors like Cuartas (2014) and Molina *et al*. (2015) mention tree species like *Leucaena leucocephala*, which are used in SPSs due to their protein content (27% raw protein). The same authors mention that animals fed with *L. leucocephala* presented reductions of 21% in methane production when compared with animals that consume the traditional diet.

There are studies that report a decrease of 20% in the production of CH_4 in diets with the inclusion of mulberry (*Morus Alba*) compared to diets based on star grass (*Cynodon plectostachyus*) (Rodríguez-Quiros *et al*., 2013). In regions like Africa, India and South America, the use of mesquite (*Prosopis* spp.) is recurrent in the SPSs. Mesquite has around 50 different species, of which all have a high protein value and are consumed by bovine, ovine and caprine livestock, among other ruminants; in addition, they are species resistant to extreme climate conditions, since they adapt to arid climates and their production is considerably high (Armijo-Najera *et al*., 2019). In addition, mesquite leaves and pods have shown to decrease the production of CH_4 *in vitro* compared to species like African moringa (*Moringa stenopetala*) or French sesban (*Sesbania sesban*) (Melesse *et al*., 2017). This is due to the content of secondary metabolites and phenolic compounds that affect the synthesis of ruminal methane and, therefore, its production (Ramírez-Rojo *et al*., 2019).

Likewise, white oak (*Quercus* sp.) is another species with high possibility of being incorporated to a SPS, since its leaves show high concentrations of secondary metabolites like condensed tannins (CT), which show positive effects on the consumption and ruminal fermentation of a fodder (Tavendale *et al*., 2005). The presence of CT contributes to the decrease in the synthesis of enteric methane in diets where the oak leaf is included (Torres-Fraga *et al*., 2018). In addition, certain studies show a reduction of 21.24% in the production of CH_4 in the enteric fermentation of ruminants *in vitro* when ground leaves of *Quercus* spp. are supplied instead of fodder of *Avena sativa* L. (Rajkumar *et al*., 2015).

Agricultural residues

In recent years, the resulting stubbles or residues from harvests have emerged as an alternative to feed livestock and decrease the production of enteric ruminal CH_4 (Caballero-Salinas *et al*., 2017). In addition, these residues tend to have a high fiber content, which represents an obstacle in the diet of humans, but not in that of ruminants. Supplementation with this type of residues decreases the costs of food without increasing the use of natural resources, thus achieving an integral use of the harvest.

In most Asian countries, production of rice (*Oryza sativa* L.) is high; the total production in Asia in 2014 was estimated at 538.8 million tons of rice straw, which is used to feed mainly the livestock in the region (Devendra and Thomas, 2002; FAO, 2014b). However, this residue presents high fiber content, which is why it is treated previously with additives like commercial urea or fibrinolytic enzymes that increase their degradability, or else, it is supplied as a dietary supplement (Phongphanith & Preston, 2016; Nguyen *et al*., 2020). The objective of pretreatment with urea, in addition to improving the digestibility, is decreasing the generation of ruminal enteric CH_4, since highly fibrous foods tend to increase the production of methanogenic bacteria (Yanti-Yayota, 2017). In this sense, Mexico cultivates close to thirty thousand ha of rice, with a yield of 4.9 t ha^{-1}, and it is expected that this production will continue in this direction until the year 2050, which generates an array of possibilities (Delgadillo-Ruíz *et al*., 2016).

In Mexico, one of the most common residues for bovine livestock feed is maize (*Zea mays* L.) stubble, which has considerable nutritional characteristics for the diet of ruminants (Prieto *et al*., 2016); in addition, maize stubble represents up to 40% of the total residue fodder in the dry season (Caballero-Salinas *et al*., 2017). This residue is offered to the animals as a dry fodder or in ensilage (Gómez-Gurrola *et al*., 2016). Authors like Carro (2018) reported a decrease of CH_4 of 13% per unit of dry matter ingested in animals fed with maize ensilage. Additionally, ensilages have been generated with maize stubble and by adding nopal (*Opuntia ficus indica*) fodder and yeasts, whose mixture causes a reduction in ruminal methanogenesis (González-Arreola *et al*., 2019).

Other elements like cotton seed meal, a yield from residues of the cotton (*Gossypium hirsutum* L.) harvest which is commonly used in ruminant diet, is supplied as paste or protein supplement (Muro-Reyes *et al*., 2017). However, its production is costly and not very accessible for livestock producers of low financial income, which is why substituting them by residues or other more affordable additives and which also help to decrease GHG would be highly desirable. In this regard, there are various studies that have considered the incorporation of other sources of fodder of high protein content that show a decrease in the production of ruminal enteric methane (Pámanes-Carrasco *et al*., 2019).

Weeds and shrubs

Some plants considered as weeds present particular characteristics inherent to the plant, such as production of secondary metabolites, which can influence the fermentation of foods consumed by the ruminant (Lezcano-Más *et al*., 2016).

In Colombia, extensive production presents low production of fodders for bovine livestock, which is why botón de oro (Mexican sunflower, *Tithonia diversifolia*) is studied as an alternative source of fodder. Although this plant is considered a weed in this country, it can present raw protein contents of 17-29%, as well as a digestibility of up to 76%. Its high contents of DM, paired with the values of digestibility, present possibilities in the decrease of production of CH_4 through the reduction of microorganisms in charge of ruminal methanogenesis

(Londoño *et al*., 2019); the inclusion of 20% of this plant as part of the fodder fraction of the total portion has managed to decrease the population of methanogens up to 50% (Mahecha-Ledesma *et al*., 2018). In Mexico, botón de oro is used in the diet of small ruminants such as sheep. There are previous studies that describe the supply of botón de oro as part of the fodder fraction in 10% and managed to manipulate the ruminal biota through the reduction in the population of methanogens and protozoa, and as consequence, the emissions of enteric CH_4 due to the increase in the population of cellulolytic bacteria (Rodríguez-García, 2017).

Forest residues

The forestry sector in Mexico generates approximately 2.8 million m^3 of residues per year, mostly sawdust. The use of sawdust as a food source in livestock production is not prohibited; however, depending on the case and the characteristics of the productive herd, it could result in a very costly practice. There are few studies that endorse the use of wood carbohydrates as a source of energy for ruminants; however, their use in cases of emergency where there is no source of fiber for the animal diet is perfectly justified; in addition, this scenario is highly probable if climate change continues with its current course (Rinne and Kuoppala, 2019). On the other hand, it has been shown that the use of sawdust favors weight gain (Fregoso-Madueño *et al*., 2017). In addition, the smaller the size of the particle is, the lignocellulose will be degraded in less time, favoring the production of volatile fatty acids (VFAs) and promoting the decrease of CH4 (Hamano *et al*., 2017).

Agroindustrial residues

The industry of transformation of agricultural products generates residues as part of its production line. The characteristics of these residues allow them to emerge as potential dietary complements in ruminant production. In this sense, Colombia is an important producer of mango (*Mangifera indica* L.) concentrate and juice; however, its seed, skin and pulp are discarded and can be susceptible of ensilage and increase the nutritional value of the fodder due to its high content of fiber carbohydrates (Borrero-Manrique *et al*., 2017). Despite there being no studies that back the effect of these residues in the production of ruminal enteric methane, it could be inferred that the use of these ensilages can decrease the production of CH_4 due to the high digestibility and high content of soluble carbohydrates that they have (Guzmán *et al*., 2019). Just in Mexico, around 54 million tons of organic residues of fruits and vegetables are generated, among which there are lime (*Citrus* spp.), pear (*Pyrus communis* L.), mango, papaya (*Carica papaya* L.), pineapple (*Annanas comosus*), banana (*Musa paradisiaca*), orange (*Citrus sinensis*), carrot (*Daucus carota*), tomato (*Solanum lycopersicum*), lettuce (*Lactuca sativa*), potato (*Solanum tuberosum* L.) and cabbage (*Brassica napus* L.) (Valdez-Vazquez *et al*., 2010). Thus, any industry that generates organic wastes becomes a potential supplier of alternative sources of feed for ruminants.

In the year 2006, the use of glycerol was legally allowed as a safe animal food according to the United States Food and Drug Administration (FDA, 2006). In addition, its inclusion in the diet of ruminants can be done through pellets, extruded or raw in a mixture with the fodder, where the concentration supplied varies according to the purity of glycerol (Hidalgo-Hernández *et al*., 2017). Likewise, glycerol has been included in the diet of ruminants as substitute of molasses (non-crystallized honeys from the process of sugar production), which generates similar concentrations of volatile fatty acids. The catabolism of glycerol in the rumen increases the formation of propionic acid, which promotes weight gain of the animal. In addition, propionate is an H^+ ion sink, which generates a natural competition with the synthesis of CH_4, favoring propionate synthesis (Martin-Nazly *et al*., 2019).

The coffee industry generates residues that could be used in animal feed. Such is the case of coffee pulp (*Coffea* sp.). Previous studies show that when coffee pulp is ensilaged with sugarcane (*Saccharum* spp.), molasses and urea, the fodder acquires nutritional values of 30 to 33% of raw protein and fiber, respectively (Flórez-Delgado and Rosales-Asensio, 2018). These characteristics allow for it to be incorporated in up to 30% of the total dry base portion without affecting the production and integrity of the livestock. However, there are no studies that encourage the effects of this type of ensilage on methanogenesis or ruminal methanogenics.

Aquatic macrophytes

The term aquatic macrophytes is given to plants that have at least the vegetative part of the plant visible at plain view, on the surface of the aquatic bodies where they grow permanently or periodically (Thomaz *et al*., 2008). In addition, macrophytes do not represent a direct competition to the diet of humans, nor do they hoard the use of natural resources. In this way, plants like aquatic lily (*Eichhornia crassipes*) present comparable nutritional values to those of a fodder of medium quality (Murillo-Ortíz *et al*., 2018); there are even studies that indicate the content of raw protein and fiber is 15.5 and 15%, respectively (Rúales *et al*., 2018). Likewise, other species such as *Oryctolagus cuniculus* have a content of raw protein and neutral detergent fiber (NDF) of 18 and 34%, respectively, in addition to a digestibility of up to 90% (Silva-Borges *et al*., 2019). Presently, the use of macrophytes happens as a source of fodder in the diet of rabbits. In a similar way, *Limnobium laevigatum* has a protein content of 16% and a fibrous part of 7% (Aponte, 2017); both species are highly reproductive in tropical zones. Additionally, Murillo-Ortíz *et al*. (2018) reported a decrease in methane when they included aquatic lily as part of the fodder fraction in *in vitro* diets. Because of this, it is possible that the inclusion of macrophytes represents a real alternative in the mitigation of GHG in livestock systems. However, the cultivation of these plants in natural aquatic bodies represents a latent risk for the existence of flora and fauna because the stagnation of these on the surface of the aquatic body prevents the passage of light and photosynthesis taking place in plants adequately; in addition, their presence consumes much oxygen, which decreases the availability of it for the native flora and fauna (Zingel *et al*., 2006). Although there are no studies that guarantee increases in the production of aquatic lily under hydroponic cultivation, there are studies that suggest its feasibility (Giri and Patel, 2012).

CONCLUSIONS

Industry in Mexico, as well as forestry and agricultural production, generate wastes whose aim is uncertain. However, the use of these can find an integral and sustainable use in livestock production. The exploitation of the diverse sources of feed can represent a sustainable alternative in the mitigation of GHG in Mexico, as well as a decrease in agricultural and industrial wastes. Additionally, the use of these residues allows for surfaces devoted to sowing sources of food for animals to change crops or decrease, as a feasible alternative against the erosion of cultivation lands. In addition, the incorporation of silvopasture systems in livestock production in Mexico could emerge as a viable option in the reduction of lands for livestock exploitation, as well as in their erosion.

REFERENCES

Aponte, H. (2017). Productividad de *Limnobium laevigatum* (Hydrocharitaceae) bajo condiciones de laboratorio. Polibotánica, 44, 157-166. Doi: 10.18387/polibotanica.44.12

Arciniegas-Torres, S.P., & Flórez-Delgado, D.F. (2018). Estudio de los sistemas silvopastoriles como alternativa para el manejo sostenible de la ganadería. Ciencia y Agricultura. 15(2): 107-116, doi: 10.1953/01228420.v15.n2.2018.8687, ISSN 0122-8420.

Armijo-Nájera, M.G., Moreno-Reséndez, A., Blanco-Contreras, E., Borroel García, V. J., & Reyes-Carrillo, J. L. (2019). Vaina de mezquite (*Prosopis* spp) alimento para el ganado caprino en el semidesierto. Revista Mexicana de Ciencias Agrícolas, 10(1), 113-122, doi: 10.29312/remexca.v10i.1728.

Borrero-Manrique, A., Cujía-Mendinueta, K., & Gutiérrez-Castañeda, C. (2017). Ensilado de mango y lactosuero: una alternativa de alimentación en vacas lecheras. Microciencia, 6, 20-37, doi: 10.18041/2323-0320

Buitrago-Guillen, M. E., Ospina-Daza, L. A., & Narváez-Solarte, W. (2018). Sistemas silvopastoriles: Alternativas en la mitigación y adaptación de la producción bovina al cambio climático. Boletín Científico, Centro de Museos de Historia Natural Universal, 22(1), 31-42, doi: 10.17151/bccm.2018.22.1.2, ISSN 2462-8190.

Caballero-Salinas, J. C., Moreno-Reséndez, A., Reyes-Carrillo, J. L., García-Valdez J.S., López-Báez, W., & Jiménez-Trujillo, J. A. (2017). Competencia del uso de rastrojo de maíz en sistemas agropecuarios mixtos en Chiapas. Revista Mexicana de Ciencias Agrícolas, 8(1), 91-104, doi: 10.29312/remexca.v8i1.74, ISSN 2007-0934.

Canizales-Velázquez, P. A., Aguirre-Calderón, O. A., Alanís-Rodríguez, E., Rubio-Camacho, E., & Mora-Olivo, A. (2019). Caracterización estructural de una comunidad arbórea de un sistema silvopastoril en una zona de transición florística de Nuevo León. Madera y Bosques, 25(2), doi: 10.21829/myb.2019.2521749.

Carro, D.M. (2018). Emisiones de metano en los animales rumiantes: influencia de la dieta. Albéitar, 220, 32-35..

Cisneros, S.P. (2019). Sistema silvopastoril: ganadería bovina ante el cambio climático [en línea]. Revista Vinculando. Disponible en: http://vinculando.org/productores/sistemas-silvopastoriles-estrategia-pertinente-para-la-ganaderia-bovina-ante-el-cambio-climatico.html

Cuartas, C. A., Naranjo, J. F., Tarazona, A. M., Murgueitio, E., Chará, J. D., Ku, J., Solorio, F. J., X-Flores, M. X., Solorio, B., & Barahona, R. (2014). Contribution of intensive silvopastoral systems to animal performance and to adaptation and mitigation of climate change. Revista Colombiana de Ciencias Pecuarias 27(2):76-94.

Delgadillo-Ruiz, O., Ramírez-Moreno, P. P., Leos-Rodríguez, J. A., Salas González, J.M., & Valdez-Cepeda, R. D. (2016). Pronósticos y series de tiempo de rendimientos de granos básicos en México. Acta Universitaria, 26(3), 23-32, doi: 10.15174/au.2016.882, ISSN 0188-6266.

Devendra, C., & Thomas, D. (2002). Crop-animal interactions in mixed farming systems in Asia. Agricultural Systems, 71 (1-2), 27-40, doi: 10.1016/S0308-521X(01) 00034-8.

FAO. (2014a). Production systems. Agriculture and Consumer protection department. Food and Agriculture Organization of the United Nations. Rome, Italy.

FAO. (2014b). FAO and Rice Market Monitor, Trade and Markets Division. Food and Agriculture Organization of the United Nations. Rome, Italy.

FAO. (2017). The future of food and Agriculture, trends and challenges. pp. 17-20. Rome, Italy.

FDA. (2006). Food and Drug Administration, Code of Federal Regulations, 21CFR582.1320, Title 21, Vol. 6.

Flórez-Delgado, D. F., & Rosales-Asensio; E. (2018). Uso del ensilaje de pulpa de café en la alimentación animal. Mundo FESC, 8(15), 73-82, ISSN 2216-0388.

Fregoso-Madueño, J. N., Goche-Télles, J. R., Rutiaga-Quiñones, J. G., González-Laredo, R. F., Bocanegra-Salazar, M., & Chávez-Simental, J. A. (2017). Usos alternativos de los residuos de la industria del aserradero. Revista Chapingo serie Ciencias Forestales y de Medio Ambiente, 23(02), 243-260, doi: 10.5154/r.rchscfa.2016.06.040, ISSN 2007-4018.

Giri, A.K., & Patel, R.K. (2012) Phytoaccumulation Potential and Toxicity of Arsenic Ions by *Eichhornia Crassipes* in Hydroponic System. Journal of Bioremediaiton and Biodegradation, 3:137, doi: 10.4172/21556199.1000137.

Gómez-Gurrola, A., Sanginés-García, L., Hernández-Ballesteros, J. A., & Benítez-Meza, J. A. (2016). Evaluación químico proximal de ensilado de maíz (variedad DK2034) en diferentes tiempos de fermentación. Educateconociencia, 7(8), ISSN 2007-6347.

González-Arreola, A., Murillo-Ortíz, M., Pámanes-Carrasco, G., Reveles-Saucedo, F., & Herrera-Torres, E. (2019). Nutritive quality and gas production of corn silage with the addition of fresh and fermented prickly pear cladodes. Journal of Animal & Plant Sciences, 40(1), 6544-6553.

Guzmán, O., Lemus-Flores, C., Bugarín, J., Bonilla, J., González-Vizcarra, V., & Ly, J. (2019). Degradabilidad ruminal *in situ* del ensilaje de desechos de mango (*Magnifera indica* L.) y rastrojos de maíz. Revista Cubana de Ciencia Agrícola, 53(2), 139-148, ISSN 0864-0408.

Hamano, Y., Takahashi, T., & Agematu, H. (2017). *In vitro* and *in vivo* ruminal fermentation of micronised Wood poder for volatile fatty acid production in beef cattle. Animal Husbandry, Dairy and Veterinary Science, 1(2), 1-6, doi: 10.15761/AHDVS.1000109, ISSN 2513-9304.

Hernández-Medrano, J.H. (2018). El metano y la ganadería bovina en México: ¿Parte de la solución y no del problema?. Agro Productividad, 11(2), 46-51.

Hidalgo-Hernández, U., Ortega-Cerrilla, M.E., Herrera-Haro, J.G., Ramírez-Mella, M., & Zetina-Córdoba, P. (2017). Glicerol una alternativa para la alimentación de rumiantes. Agro Productividad, 11(5), 124-129.

Lezcano-Más, Y., Soca-Pérez M., Roque-López, E., Ojeda-García, F., Machado-Castro, R., & Fontes-Marrero, D. (2016). Forraje de *Tithonia diversifolia* para el control de estrongílidos gastrointestinales en bovinos jóvenes. Pastos y Forrajes, 39(2), 133-138, ISSN 0864-0394.

Londoño, J., Mahecha-Ledesma, L., & Angulo, J. (2019). Desempeño agronomíco y valor nutritivo de *Tithonia diversifolia* (Hemsl) A gray para la alimentación de bovinos. Revista Colombina de Ciencia Animal Recia, 11(1), 28-41, doi: 10.24188/recia.v0.n0.2019.693.

Mahecha-Ledesma, L., Angulo, J., & Barragán-Hernández, W. (2018). Calidad nutricional, dinámica fermentativa y producción de metano de arreglos silvopastoriles. Agronomía Mesoamericana.28(2). 371-387, doi: 10.15517/ma.v28i2.22750.

Martin-Nazly, Y., De Jesús-Rojas, G., Arenas, E. N., & Herrera-Franco, V. (2019). Nutrional alternatives to reduce methane gas emissions by cattle and their effect on global warming. Revista Ciencias Agropecuarias, 3(1), 8-17.

Martínez-Prado, M.A. (2016). Estimación de las emisiones de gases de efecto invernadero para el estado de Durango, México. Revista Mexicana de Ingeniería Química, 15(2), 575-601.

Melesse, A., Steingass H., Schollenberger, M., Holstein, J., & Rodehutscord, M. (2017). Nutrient compositions and *in vitro* methane production profiles of leaves and whole pods of twelve tropical multipurpose tree species cultivated in Ethiopia. Agroforesty Systems, 93, 135-147, doi: 10.1007/s10457-017-0110-9.

Molina, I.C, Donney, G., Montoya, S., Rivera, J.E, Villegas, Chará, J., & Barahona, R. (2015). La inclusión de *Leucaena leucocephala* reduce la producción de metano de terneras Lucerna alimentadas con *Cynodon plectostach* y *Megathyrsus maximus*. Livestock Research for Rural Development, 27(5), 96.

Muro-Reyes, A., Arzola-Álvarez, C., Rodríguez-Muela, C., Corral-Luna, A., Gutiérrez-Bañuelos, H., Herrera-Torres, E., Gutíerrez-Piña, F. J., & Espinoza-Canales A. (2017). Cinética de degradación ruminal *in vitro* de dietas con manzarina y rastrojo de maíz en ovinos. Acta Universitaria, 27(02), 17-23, doi: 10.1517/au.2017.1200, ISSN 0188-6266.

Murillo-Ortíz, M., Herrera-Torres, E., Corral-Luna, A., & Pámanes-Carrasco, G.A. (2018). Effect of inclusion of graded level of water hyacinth on *in vitro* gas production kinetics and chemical composition of alfalfa hay based beef cattle diets. Indian Journal of Animal Research, 2018;(8):52, 1298- 1303, doi: 10.18805/ijar.11417, ISSN 2071-7024.

Nguyen, D.V., Vu, C.C., & Nguyen, T.V. (2020). The Current Utilisation and Possible Treatments of Rice Straw as Ruminant Feed in Vietnam: A Review. Pakistan Journal of Nutrition, 19(3), 91-104, doi: 10.3923/pjn.2020.91.104

Pámanes-Carrasco, G., Murillo-Ortíz, M., Herrera-Torres, E., & Reyes-Jáquez, D. (2019). Livestock Production: Nonconventional Feedstuffs and Alternative Additives. *In*: Livestock Health and Farming, edited by Abubakar M. Intechopen publishers, London, UK.

Párraga-Alava, C., Barre-Zambrano, R., Dueñas-Rivadeneira, Á., Muñoz-Murillo, J., & Zambrano-Vélez, M. (2018). Elaboración de harina a partir de *Eichhornia Crassipes* utilizando diferentes métodos de deshidratación. PRO SCIENCES: Revista de producción, ciencias e investigación. 2(7), 3-6, doi: 10.29018, ISSN 2588-1000.

Phongphanith, S., & Preston, T.R. (2016). Effect of rice-wine distillers by product and biochar on growth performance and methane emissions in local "Yellow" cattle feed ensiled cassava root, urea, cassava foliage and rice Straw. Livestock Research for Rural Development, 28, 178.

Prieto, U.B, Castillo, Y.C, Barrera, O.R, Flores, O.J, Ortiz, M.I, & Álvarez, A. (2016). Efecto de un cultivo de levadura (*Candida norvegenesis*), en el comportamiento productivo de becerros criollos engordados con una dieta a base de rastrojo de maíz. Instituciones co-organizados, 134.

Puebla-Albiter, S., Rebollar-Rebollar, S., Gómez-Gómez, T., Hernández-Martínez, J., & Guzmán-Soria, E. (2018). Factores determinantes de la oferta regional de carne bovina en México. Región y Sociedad, 30(72), doi: 10.22198/rys.2018.72.a895, ISSN 2448-4849.

Rajkumar, K., Bhar, R., Kannan A., Jadhav, R.V., Singh, B., & Mal, G. (2015). Efecto de remplazar el forraje de avena con hojas de roble frescas y picadas en la fermentación ruminal *in vitro*, la digestibilidad y la energía metabolizable. Mundo Veterinario, 8(8), 1021, doi: 10.14202/vetworld.2015, ISSN 1021-1026.

Ramírez-Ramírez, H. A. (2016). Aplicación de Principios de Nutrición de ganado lechero en la producción de leche y carne con ingredientes tradicionales. Ceiba, 54(1), 66-71, doi: 10.5377/ceiba.v54i1.2781.

Ramírez-Rojo, M.I., Vargas-Sánchez, R.D., Hernández-Martínez, J., Martínez-Benavidez, E., Sánchez-Escalante, J.J., Torrescano-Urrutia, G.R., & Sánchez-Escalante, A. (2019). Actividad antioxidante de extractos de hoja de mezquite (*Prosopis velutina*). Biotecnia, 21(1), 113-119, doi: 10.18633/biotecnia.v21i1.821.

Rinne, M., & Kuoppala, K. (2019). Feeds for ruminant from forests? *In*: Proceedings of the 10th Nordic Feed Science Conference, Uppsala, Sweden, 11-12, pp.79-86 ref.36.

Rodríguez-García, I. (2017). Potencialidades de *Tithonia diversifolia* (Hemsl.) Gray en la alimentación animal. Livestock Research for Rural Development, 29,4.

Rodríguez-Quiros, T.A., Mancipe, E.A., Mestra, L.I., Vásquez-Carreño, D.R., Avellaneda, Y., Ariza-Nieto C. J., & Mayorga, O. L. (2013). Effect of addition of crude extracts vegetable from *Sambucus nigra*, *Tithonia diversifolia* and *Morus alba* on the total gas production and production of methane under anaerobic in vitro conditions. Revista Colombiana de Ciencia Pecuaria, 26, 433, ISSN 2256-2958.

Rúales, D., Carlos, A., Bedoya-Mejía, O., & Millán-Cardona, L. (2018). Silo from víscera of rainbow trout (*Oncorhynchus mykiss*) as a suplement for sheep feeeding. Revista producción más limpia, 13(2), 29-36, doi: 10.22507/pml.v13n2a4, ISSN 1909-0455.

Saynes-Santillán, V., Etchevers-Barra, J.D., Paz-Pellat, F., & Alvarado-Cárdenas, L.O. (2016). Emisiones de gases de efecto invernadero en sistemas agrícolas de México. Terra Latinoamericana, 34(1), 83-96, ISSN 2395-8030.

SIAP. (2018). Día nacional de la ganadería: una de las actividades económicas más importantes del país. Servicio de Información Agroalimentaria y Pesquera Gobierno de México.

Silva-Borges, A.P., Tannus-Menezes, L., dos Santos-Lázaro, A., Cavatino-Herrera, G., Lucio-Franca, G., Andrade-de-Paula, S.Y., Nakamura-Hiraki, K.R., & Carneiro-de-Silva, F.O. (2019). Topography, irrigation, and histology of the thyroid gland of Zealand rabbits (*Oryctolagus cuniculus* Linnaeus, 1758). International Journal of Advanced Engineering Research and Science, 6(3), doi: 10.22161/ijaers.6.3.29, ISSN 2456-1908.

Tavendale, M., Meagher, L.P., Pacheco, D., Walker, N., Attwood, G., & Sivakumaran, S. (2005). Methane production from *in vitro* rumen incubations with *Lotus pedunculatus* and *Medicago sativa*, and effects of extractable condensed tannin fractions on methanogenesis. Animal Feed Science and Technology, 123(1), 403-419. Doi: 10.1016/j.anifeedsci.2005.04.037

Thomaz, S.M., Esteves, F.A., Murphy, K.J., Medeiros-dos-Santos, A., Caliman, A., & Guariento, R. (2008). Aquatic macrophytes in the tropics: ecology of populations and communities, impacts of invasión and use by man. *In*: Encyclopedia of Life System Support; Del-Claro, K., Scarano, F.R., & Luettge, H., editors. UNESCO.

Torres-Fraga, K., Herrera-Torres, E., Reyes-Estrada, O., & Murillo-Ortíz, M. (2018). Producción de gas, degradabilidad y fermentación ruminal *in vitro* de dietas para bovinos de carne con la inclusión de hojas de encino (*Quercus* sp.). Agro Productividad, 11(6), 120-127.

Valdez-Vazquez, I., Acevedo-Benítez, J. A., & Hernández-Santiago, C. (2010). Distribution and potential of bioenergy resources from agricultural activities in Mexico. Renewable and Sustainable Energy Reviews, 14(7), 2147–2153, doi: 10.1016/j.rser.2010.03.034

Valencia-Trujillo, F. L., & Rojas-López, T. A. (2019). Mecanismos de nutrición para la reducción del efecto invernadero. ECAPMA, 2, 1-11.

Van-Hung, N., Maguyon-Detrás-Monet, C., & Victoria-Migo, M.Q. (2020). Rice Straw Overview: Availability, propierties and management practices in. Sustainable Rice Straw Management. (1-13), doi: 10.1007/978-3-030-32373-8_1.

Vélez, V., Obando, A., San-Martín, F., Olazabal, J., Pacheco, J., & Franco, F. (2014). Relación entre el consumo de materia seca y la estimación de la emisión de metano en vacunos lecheros diferenciada por sistema de producción y fase de lactancia en la irrigación Majes, Arequipa, Perú. Primera conferencia de gases de efecto invernadero en sistemas agropecuarios de Latinoamérica (GALA). Osorno, Chile

Villanueva, C., Casasola, F., & Detlefsen, G. (2018). Potencial de los sistemas silvopastoriles en la mitigación al cambio climático y en la generación de múltiples beneficios en fincas ganaderas de Costa Rica. 1era edición.

White, R.R., Román-García, Y., Firkins, J.L., VandeHaar, M.J., Armentano, L.E., Weiss, W.P., McGill, T., Garnett, R., & Hanigan, M.D. (2017). Evaluation of the National Research Council (2001) dairy model and derivation of new prediction equations. 1. Digestibility of fiber, fat, protein, and nonfiber carbohydrate. Journal of Dairy Science, 100, 3591-3610, doi: 10.3168/jds.2015-10800

Yanti, Y., & Yayota, M. (2017). Agricultural by-products as feed for ruminants in tropical área: nutritive value and mitigating methane emisión. Reviews in Agricultural Science, 5, 65-76, doi: 10.3389/fmicb.2016.00132.

Zingel, P., Noges, P., Tukivene, L., Feldmann, T., Järvalt, A., Tonno, I., Agasild, H., Tammert, H., Luup, H., Salujoe, J., & Noges, T. (2006). Ecological processes in macrophyte- and phytoplankton-dominated shallow lakes. Proceedings of the Estonian Academy of Science, Biology and Ecology, 55(4): 280-307. ISSN 1736-7530