

Small Ruminant Production

Subjects: **Zoology**

Contributor: Rafael Arturo Torres-Fajardo , Pedro Geraldo González-Pech , Carlos Alfredo Sandoval-Castro , Juan Felipe de Jesús Torres-Acosta

The background and context of Small Ruminant production on rangelands is presented.

Sheep goat small ruminants Rangelands production health

low deciduous forest gastrointestinal nematodes plant secondary compounds

1. Introduction

Projections suggest that by 2030, domestic ruminant numbers in developing countries will exceed those of the entire planet in 2000 [1]. Meeting the booming demand for livestock and livestock products, therefore, requires the development of more efficient, sustainable and alternative feeding systems to support the future forage requirements, which cannot be sustained by single species grass-feeding systems [2]. Rangelands are native vegetation environments with heterogeneous vegetation cover including grasses, creepers, shrubs and trees. These ecosystems have served as a source of food for livestock for centuries [3][4]. In many parts of the world, these systems provide the main forage resource for traditional livestock [5][6] or represent the only commodity available to very poor communities [7], affecting the livelihoods of millions of people.

However, commonly most people consider rangelands as a “waste-land” because its conditions are unfit for many human agricultural activities [8][9]. In some parts of the world, wealthy farmers destroy rangelands to introduce grass plantations, which are considered as the “way forward” for the modern production of milk and meat from ruminants [10][11][12]. Thus, most common people look at the native vegetation as a useless resource, including plants commonly classified as “weeds”, which are used by the poor and the backward. However, those ideas must be countered from the standpoint of solid scientific knowledge. Rangelands are valuable in their own right for the large number of organisms they include as well as their complex interactions, which we are only beginning to discover and understand. Some rangeland ecosystems, such as the low deciduous forest (LDF) include plants that are important for carbon sequestration, building, ceremonial activities, medicinal purposes, crafting materials, fuel and production of nectar and pollen for beekeeping [13][14][15]. Furthermore, recent studies exploring the nutritional value of the plant species in the LDF also cast light on its potential value for ruminant livestock. Thus, efforts to incorporate strategies aimed at maintaining long-term productivity and convert native vegetation biomass into valuable food products for humans continues to be a focus of animal scientists [4][12].

In this context, the LDF could represent a viable scenario for research purposes. The LDF vegetation in México represents an important source of nutrients for most small ruminant flocks, and in some cases represents the only source of feed [13][15]. Over 200 LDF plant species have been reported to possess feeding potential for domestic ruminants [16]. However, coping with such a level of heterogeneity may not represent an easy task for sheep and goats, given that, on a daily basis, they are confronted with the challenge of establishing a feeding strategy through the selection of various plants containing different arrays of nutrients and plant secondary compounds (PSC) in different concentrations in large and constantly changing permutations [1][17][18]. Nevertheless, smallholders have taken advantage of the ability of small ruminants to thrive in these ecosystems, harvesting (grazing/browsing) its biomass to obtain their nutrient requirements. Sheep and goats have been in a coevolutionary “arms race” against plant defense mechanisms for millennia. Hence, they need to develop adaptive mechanisms [19][20][21] not only aimed at coping with diverse levels and concentrations of nutrients and PSC present in plants, but also at obtaining certain benefits after their consumption.

Indeed, a large body of research has focused on the capacity that some PSC have to alleviate or prevent animal diseases. Considering that conventionally, the gastrointestinal nematodes (GIN) infections are considered as one of the most significant constraints for small ruminants feeding on natural scenarios [22][23][24], efforts have been directed to assess, under in vitro and in vivo approaches, the anthelmintic (AH) effect of some PSC against the different life stages of GIN. The bulk of the research has been directed at identifying the AH activity of the condensed tannins (CT) [25][26][27][28][29][30][31], while some PSC, like saponins, flavonoids, terpenoids, alkaloids and sesquiterpene lactones, have also been studied more recently [32][33][34]. In the meantime, the growing evidence on the relationships between herbivores, plants, PSC and GIN served as the springboard for the introduction to the novel “nutraceutical” concept in the veterinary sciences. According to Hoste et al. [35], a nutraceutical can be defined as a livestock feed which combines nutritional value with beneficial effects on animal health. The latter situation bolsters the idea that native plants harvested by sheep and goats could be considered as nutraceuticals, since they inherently contain different arrangements of nutrients and PSC. To date, however, there are few approaches to identifying plants with nutraceutical properties despite the large biodiversity of rangelands, which may be partly due to the lack of specific guidelines [35]. Considering the latter, the identification of the nutraceutical value of plant species would be a key factor to consider when developing feeding strategies and management schemes that promotes the sustainable use and preservation of rangelands.

2. Unravelling the Heterogeneous Context of the Low Deciduous Forest

The LDF is the most widely distributed tropical vegetation of México, and even the largest of this type in Latin América [36]. It has been estimated that approximately 60% of the plant species of this ecosystem are exclusively from México [37], hence, its ecologic and conservation value has been highlighted [38][39][40]. The LDF covers approximately 8% of México's surface area (~157,000 km²), being present in some portions of the states of Baja California, Campeche, Chiapas, Colima, Estado de México, Guerrero, Michoacán, Morelos, Nayarit, Oaxaca, Puebla, Sonora, Tamaulipas, Veracruz and Yucatán [41]. In Yucatán, the LDF is the most widely distributed plant

community and, along with the medium semi-deciduous forest, typifies the physiognomy of the state's landscape, covering an extension of ~20,000 km² [42] which are distributed in the center, west and extend in a non-uniform strip from the northeastern portion of that state, reaching the neighboring Campeche state. The LDF thrive in sub-humid, semi-arid and warm climates, with a median annual temperature above 20 °C and an average annual rainfall between 700 and 1200 mm [36][40], and is characterized, initially, for its arboreous component not exceeding 15 m in height, as well for the high percentage (>70%) of plant species with deciduous leaf's falling during the dry season [38]. Thus, the interannual rainfall is the primary determinant of foliage productivity [4][43].

2.1. Botanical and Nutritional Components of the Low Deciduous Forest

The LDF include plant species with nutritional features that are employed by small ruminant farmers (as grazing/browsing paddocks or in cut and carry systems). The LDF serves as a source of foliage during the dry and the rainy season, with plants of medium to high nutritional value, in various life forms and heights. Several species have been reported to contain PSC which could provide an added health value, leading to an enhanced animal productivity [14]. According to some estimates, the number of plant species in the Yucatán peninsula reaches about 2200 [44]. In a 10-year survey, it was determined that Mayan communities use 196 plant species as forage (for cattle, sheep, goats, pigs and poultry), amongst which 139 were herbaceous, 17 were shrubs, 35 were trees and 2 were palms [3]. Similarly, the LDF vegetation in the center-north region of Yucatán is comprised of 123 plant species belonging to 41 plant families [41]. Despite this plethora of botanic families, the Fabaceae is the best represented [36]. The presence of other families, such as Convolvulaceae, Malvaceae, Asteraceae, Polygonaceae, Rubiaceae, Boraginaceae, Verbenaceae, Euphorbiaceae, Acanthaceae, Cactaceae, Burseraceae, Compositae, Malpighiaceae and Anacardiaceae, was also reported [36][42].

A common feature of the Fabaceae (also known as Leguminosae) family, is their high content of crude protein (CP) and PSC [42], although plants from other families could also contain high macronutrient or PSC contents. For instance, *Gymnopodium floribundum* and *Neomillspaughia emarginata* (Polygonaceae) present 37.6 and 37.5% CT, respectively, and conversely, *Viguiera dentata* (Asteraceae) and *Ipomoea crinicalyx* (Convolvulaceae) present 29.6 and 23.7% CP, respectively. Previous studies detailed the macronutrient and PSC characterization of plant fodder [45][46] and pods [47] consumed by small ruminants in the LDF. On the other hand, vegetation from the LDF, normally present low energy content, which is mainly provided by grass species. This situation is worsened because the latter have a marked seasonal availability, with most dying during the dry season [48]. Considering these particular features, we can state that LDF represents a source of high dietary CP with a limiting energetic value. Hence, energy-rich dietary supplementation has been proposed to optimize its use by sheep [49] and goats [50].

2.2. Plant Secondary Compounds in the Low Deciduous Forest

According to Estell et al. [1], the literature is replete with studies on the role of PSC in herbivores for both domestic livestock and wildlife on every continent. Although a thorough analysis of the PSC nature is beyond the scope of the present review, we want to point out some key aspects that deserve to be addressed in order to build a more

comprehensive panorama of these compounds, the context in which they are present and the animal species that eventually incorporate them into their diets.

Plants, as sessile organisms, have no chance of escaping attacks from other organisms, so they must employ other strategies to defend themselves [17], including a number of chemical components known as “natural compounds”, “phytochemicals”, “plant secondary compounds” or “specialized metabolites”, the last two terms being the most accepted within the veterinary and ecological sciences, respectively [31][51]. The PSC are synthesized in the whole spectrum of the plant kingdom and their presence and concentration in a given plant is influenced by genetics, phenology, and a variety of biotic and abiotic factors [21]. Estimates suggest there are up to 200,000 PSC produced by different plants in response to particular challenges [52]. However, some authors argue that this number is probably a gross underestimation given the low number of plant species investigated to date and the low concentrations of some specialized PSC, which in turns affects the effectiveness of their detection [51].

From an ecological perspective, PSC represent adaptations to specific situations that facilitate interactions with the biotic and abiotic environment, including the essential role of chemical defenses against pathogens and herbivory [17][51][52][53]. It worth mentioning that the term *herbivore* comprises a wide range of species, including insects, birds, reptiles, non-ruminant and ruminant mammals. Indeed, plants and insects have coexisted for at least 350 million years [54], while the current ruminant families entered in the chronology of ecosystems only 18–23 million years ago [55], which likely modifies the dynamics and PSC production in landscapes by incorporating a different type of pressure than that of insects (ruminant liveweights ranges from about 2 to more than 800 kg) [54]. Therefore, the long-term coevolution between herbivores and PSC necessarily entails the triggering of adaptive responses, which correspond mainly to behavioral and physiological mechanisms that involve both pre-ingestive and post-ingestive processes. Those same mechanisms were used to their full extent when domestic ruminants were introduced to the American continent or to islands such as Australia in more recent years, forcing animals to implement different adaptation mechanisms that have only evolved within the last 500 years [6]. We encourage readers to consult reviews in this subject in order to gain a complete perspective of the mechanisms by which ruminants cope with PSC [18][21][56]. Under this context, we emphasize and support the way of thinking of Mueller-Harvey et al. [31] and Villalba et al. [57] when they argued that PSC are components with multiple and interrelated functions looking to improve resilience, provide plasticity and support the development and interaction of plants with their environment.

2.3. The Unavoidable Occurrence of Gastrointestinal Nematodes in the Low Deciduous Forest

Regardless of place and climatic conditions, gastrointestinal nematodes (GIN) are a common component of grazing vegetation systems used by sheep and goats worldwide. When domestic ruminants were introduced to the LDF, they also brought their own internal and external parasites. Those parasites also had to become adapted to the new conditions to which they were exposed, particularly the free-living phases that must survive outside the host [6]. The level of success in the survival of parasites in different environmental conditions is the main cause of differences in the array of parasite species present in each region of the world. Thus, although the presence of GIN is common for all the grazing ruminant production systems, the species present in each region vary considerably

[58][59]. Under the hot sub-humid conditions of the LDF in México, small ruminants are mainly infected with *Haemonchus contortus* in the abomasum, *Trichostrongylus colubriformis* in the small intestine and *Oesophagostomum columbianum* in the large intestine, with the eventual presence of *Strongyloides* spp., *Trichuris* spp. and *Cooperia* spp. [60]. The mismanagement of grazing schemes may lead to a vicious cycle of land over-exploitation, in which plants' equilibrium is altered by ruminant herbivory and substantial quantities of infective stages accumulate within the pastures. Ultimately, the accumulation of unsustainable GIN burdens inside the host triggers a condition which is recognized as one of the main constraints for small ruminant production throughout the world [61][62].

There are some noteworthy key epidemiological processes related to the development and viability of GIN that take place within the pastures. Initially, the ruminant host sheds GIN eggs via fecal excretion, and after that, eggs hatch in the feces, releasing larvae, which undergo a moulting process from larvae 1 to larvae 2, to finally become a sheathed larva (on pasture) able to re-infect hosts (larvae 3 or L₃). This process is largely influenced by some environmental factors, including temperature, humidity and solar radiation [63][64]. Additionally, it is important to consider that both the nutritional resources and the infective L₃ are unevenly distributed in both space and time [65][66]. Thus, complex decisions must be taken by ruminants in order to obtain enough nutrients while avoiding higher intake of L₃ [67].

It is assumed that L₃ are associated with the grass species, but not with shrubs or higher stratum plant species. Experiments conducted in grass monocultures showed that 80% of L₃ were located in the first 5 cm above the ground [68], although others found a homogeneous distribution of L₃ in different pasture strata [69]. A recent study performed in Brazil reported no differences in L₃ content between two grazing systems (grass vs. grass + legumes) using the pasture larval count technique (PLCT). However, that study used a short legume that grew mixed within the grass [70]. In heterogeneous vegetation systems such as the LDF, the dynamics of L₃ migration may represent a distinct pattern. Recent tracer studies suggested that the consumption of high strata fodder (>50 cm) was negatively associated with GIN infection of tracer kids [71]. Sheep and goat production in LDF is usually developed without proper plant management other than occasional pruning. Therefore, tracer studies are preferred over the PLTC due to the complexity in the architecture of plants in the LDF, where animals harvest leaves of different plant species at different heights of strata.

Concomitant with the relationship between herbivores and PSC, a co-evolution process of 10–20 million years between herbivores and GIN occurred [72]. Thus, from an evolutionary perspective, both host and GIN shaped a long-term relationship where a large proportion of animals within a flock can endure moderate loads of GIN without compromise to their health or productive status. As a consequence, only a few animals have unsustainable GIN burdens which cannot be tolerated. The latter has been referred as “aggregation” and represents a general law of parasite ecology, where the majority of hosts are infected with few or no parasites, whereas a small proportion of hosts are infected with many parasites [73][74]. For the southeast of México, Torres Acosta et al. [75][76] showed that 75–80% of animals in flocks had low GIN burdens and are able to maintain their productive performance without apparent negative effects. Some of those animals with low GIN infections are capable to limit their infections through their immune system and are known to be “resistant” to infections [77][78]. Meanwhile, amongst those

animals with GIN infections there are several ones capable of enduring the negative impact of their natural GIN infection, while keeping their ability to grow and reproduce, and these are known as "resilient" [77][78]. Considering these concepts, it is important to emphasize the notion that GIN infections in small ruminants on production systems based on grazing/browsing natural vegetation are unavoidable, but also biologically affordable.

2.4. The Unraveled Context of the Low Deciduous Forest

It is difficult to generalize any concept or paradigm in a context where different levels and concentrations of plants, nutrients, PSC and GIN vary over space and time, and where the only constant is change. Nonetheless, evolutionary trends shaped many interactions between the aforementioned components. The LDF dynamics show a multifactorial mechanism in which plants contain nutrients and defense strategies allowing them to interact with their environment, and these chemical strategies also enable plants to survive to its environments and control herbivory at some level. On the other hand, LDF also bring benefits after their consumption, which allows herbivores to coexist with certain GIN populations, and the latter are returned to the environment through fecal excretion. A long-term consequence of this adaptive process could be the notion that LDF have up to 260 plant species with feeding potential for ruminants [16], amongst which roughly 80 are been consumed by sheep and goats, as confirmed through observational studies [79][80][81]. This scenario would increase its complexity if the farmers practices in terms of using/managing their LDF grazing/browsing areas is to be considered.

3. Implications

Small ruminant production in the low deciduous forest has been traditionally considered as a productive system with low feeding value and income level. However, this system is still used by many livestock producers throughout tropical America. The inherent heterogeneity of the low deciduous forest could be used, in a rational way, to improve the nutrition and health of sheep and goats through the linkage of many scientific disciplines such as ecology, agronomy, ethology, nutrition, parasitology and chemistry. Thus, the proper knowledge and use of plants from the low deciduous forest, and by extention from other ecosystems, should help in the design of sustainable production systems with an improve use of native resources, reducing the use of external xenobiotics and, as a result, reducing their environmental impact.

References

1. Estell, E.; Havstad, K.M.; Cibilis, A.F.; Fredrickson, E.L.; Anderson, D.M.; Schrader, T.S.; James, D.K. Increasing shrub use by livestock in a world with less grass. *Rangel. Ecol. Manag.* 2012, 65, 553–562, doi:10.2111/rem-d-11 -00124.1.
2. McDermott, J.; Staal, S.J.; Freeman, H.A.; Herrero, M.; Van de Steeg, J.A. Sustaining intensification of smallholder livestock systems in the tropics. *Livest. Sci.* 2010, 130, 95–109, doi:10.1016/j.livsci.2010.02.014.

3. Flores, ; Bautista, F. Knowledge of the Yucatec Maya in seasonal tropical forest management. *Rev. Mex. Biodivers.* 2012, 83, 503–512, doi:10.22201/ib.20078706e.2012.2.1243.
4. Accatino, ; Sabatier, R.; De Michele, C.; Ward, D.; Wiegand, K.; Meyer, K.M. Robustness and management adaptability in tropical rangelands: A viability-based assessment under the non-equilibrium paradigm. *Animal* 2014, 8, 1272–1281, doi:10.1017/S1751731114000913.
5. Lund, G. Accounting for the world's rangelands. *Rangelands* 2007, 29, 3–10, doi:10.2111/1551-501X(2007)29[3:AFTWR]2.0.CO;2.
6. Alonso-Díaz, A.; Torres-Acosta, J.F.J.; Sandoval-Castro, C.A.; Campbell, W.B. Controlling the Introduction and Augmentation of Parasites in and on Domesticated Livestock. In *Sustainable Food Production Includes Human and Environmental Health*; Bruce Campbell, W., López-Ortíz, S., Eds.; Springer: Dordrecht, The Netherlands, 2014; pp. 191–228.
7. Dumanski, ; Desjardins, R.L.; Lal, R.; Rosegrant, M.; de Freitas, L.; Lander, J.N.; Gerber, P.; Steinfeld, H.; Verchot, L.V.; Schuman, G.E.; et al. Supporting evidence for greenhouse gas mitigation in agriculture. In *Applied Agrometeorology*; Stötger, K., Ed.; Springer: Berlin/Heidelberg, Germany, 2010; pp. 989–996.
8. Ayatunde, ; de Leeuw, J.; Turner, M.D.; Said, M. Challenges of assessing the sustainability of (agro)-pastoral systems. *Livest. Sci.* 2011, 139, 30–43, doi:10.1016/j.livsci.2011.03.019.
9. Oosting, J.; Udo, H.M.J.; Viets, T.C. Development of livestock production in the tropics: Farm and farmers' perspectives. *Animal* 2014, 8, 1238–1248, doi:10.1017/S1751731114000548.
10. Hubert, ; Meuret, M.; Bonnemaire, J. Shepherds, sheep and forest fires: A reconception of grazinglands. In *Handbook of Transdisciplinary Research*; Hadorn, G.H., Hoffmann-Riem, H., Biber-Klemm, S., Grossenbacher-Mansuy, W., Joye, D., Pohl, C., Wiesmann, U., Zemp, E., Eds.; Springer Science + Business Media BV: Dordrecht, The Netherlands, 2008; pp. 103–126.
11. Hubert, ; Deverre, C.; Meuret, M. The rangelands of southern France: Two centuries of radical change. In *The Art and Science of Shepherding*; Meuret, M., Provenza, F.D., Eds.; Acres USA: Austin, TX, USA, 2014; pp. 27–43.
12. Udo, M.J.; Aklilu, H.A.; Phong, L.T.; Bosma, R.H.; Budisatria, I.G.S.; Patil, B.R.; Samdup, T.; Bebe, B.O. Impact of intensification of different types of livestock production in smallholder crop-livestock systems. *Livest. Sci.* 2011, 139, 22–30, doi:10.1016/j.livsci.2011.03.020.
13. Torres-Acosta, F.J.; Alonso-Díaz, M.; Hoste, H.; Sandoval-Castro, C.A.; Aguilar-Caballero, A.J. Positive and negative effects in goat production arising from the intake of tannin rich forage. *Trop. Subtrop. Agroecosyst.* 2008, 9, 83–90.
14. Torres-Acosta, F.J.; González-Pech, P.G.; Ortíz-Ocampo, G.I.; Rodríguez-Vivas, R.I.; Tun-Garrido, J.; Ventura-Cordero, J.; Castañeda-Ramírez, G.S.; Hernández-Bolio, G.I.; Sandoval-Castro, C.A.;

Ortega-Pacheco, A. Revalorizando el uso de la selva baja caducifolia para la producción de rumiantes. *Trop. Subtrop. Agroecosyst.* 2016, 19, 3–80.

15. Ventura-Cordero, ; Sandoval-Castro, C.A.; González-Pech, P.G.; Torres-Acosta, J.F.J. El follaje de la selva baja caducifolia como alimento nutracéutico y su potencial antihelmíntico en pequeños rumiantes. *AIA* 2017, 21, 55–67.

16. Flores, ; Vermont, R.; Kantún, J. Leguminosae diversity in the Yucatán peninsula and its importance for sheep and goat production. In *Herbivores: The Assessment of Intake, Digestibility and the Roles of Secondary Compounds*; Sandoval-Castro, C.A., Deb Hovell, F.V., Torres-Acosta, J.F.J., Ayala-Burgos, A., Eds.; Nottingham University Press: Nottingham, UK, 2006; pp. 291–299.

17. Mithofer, ; Boland, W. Plant Defense Against Herbivores: Chemical Aspects. *Ann. Rev.* 2012, 63, 431–450, doi:10.1146/annurev-arplant-042110-103854.

18. Moore, D.; Wiggins, N.L.; Marsh, K.J.; Dearing, M.D.; Foley, W.J. Translating physiological signals to changes in feeding behavior in mammals and the future effects of global climate change. *Anim. Prod. Sci.* 2015, 55, 272–283, doi:10.1071/AN14487.

19. Janis, An evolutionary history of browsing and grazing ungulates. In *The Ecology of Browsing and Grazing*; Gordon, I.J., Prins, H.H.T., Eds.; Ecological Studies 195; Springer: Berlin/Heidelberg, Germany, 2008; pp. 21–45.

20. Clauss, ; Kaiser, T.; Hummel, J. The morphophysiological adaptations of browsing and grazing mammals. In *The Ecology of Browsing and Grazing*; Gordon, I.J., Prins, H.H.T., Eds.; Ecological Studies 195; Springer: Berlin/Heidelberg, Germany, 2008; pp. 47–88.

21. Estell, Coping with shrub secondary metabolites by ruminants. *Small Rum. Res.* 2010, 94, 1–9, doi:10.1016/j.smallrumres.2010.09.012.

22. Molento, B.; Fortes, F.S.; Pondelek, D.A.S.; Borges, F.A.; Chagas, A.C.S.; Torres-Acosta, J.F.J.; Geldfoh, P. Challenges of nematode control in ruminants: Focus on Latin America. *Vet. Parasitol.* 2011, 180, 126–132, doi:10.1016/j.vetpar.2011.05.033.

23. Miller, E.; Kaplan, R.M.; Pugh, D.G. Internal parasites. In *Sheep and Goat Medicine*, 2nd ed.; Pugh, D.G., Baird, A.N., Eds.; Saunders Elsevier: Maryland Heights, MO, USA, 2012; Volume 2, pp. 106–125.

24. Charlier, ; van der Voort, M.; Kenyon, F.; Skuce, P.; Vercruyse, J. Chasing helminths and their economic impact on farmed ruminants. *Trend. Parasitol.* 2014, 30, 361–367, doi:10.1016/j.pt.2014.04.009].

25. Makkar, P. Effects and fate of tannins in ruminant animals, adaptation to tannins, and strategies to overcome detrimental effects of feeding tannin-rich feeds. *Small Rum. Res.* 2003, 49, 241–256, doi:10.1016/S0921-4488(03)00142-1.

26. Mueller-Harvey, Unravelling the conundrum of tannins in animal nutrition and health. *J. Sci. Food Agric.* 2006, 86, 2010–2037, doi:10.1002/jsfa.2577.

27. Alonso-Díaz, A.; Torres-Acosta, J.F.J.; Sandoval-Castro, C.A.; Hoste, H. Tannins in tropical tree fodders fed to small ruminants: A friendly foe? *Small Rum. Res.* 2010, 89, 164–173, doi:10.1016/j.smallrumres.2009.12.040.

28. Hoste, ; Martínez-Ortíz-de-Montellano, C.; Manoralaki, F.; Brunet, S.; Ojeda-Robertos, N.; Fourquaux, I.; Torres-Acosta, J.F.J.; Sandoval-Castro, C.A. Direct and indirect effect of bioactive tannin-rich tropical and temperate legumes against nematode infections. *Vet. Parasitol.* 2011, 186, 18–27, doi:10.1016/j.vetpar.2011.11.042.

29. Muir, The multi-faceted role of condensed tannins in the goat ecosystem. *Small Rumin. Res.* 2011, 98, 115–120, doi:10.1016/j.smallrumres.2011.03.028.

30. Piluzza, ; Sulas, L.; Bullita, S. Tannins in forage plants and their role in animal husbandry and environmental sustainability: A review. *Grass Forage Sci.* 2014, 69, 32–48, doi:10.1111/gfs.12053.

31. Mueller-Harvey, ; Bee, G.; Dohme-Meier, F.; Hoste, H.; Karonen, M.; Kölliker, R.; Lüscher, A.; Niderkorn, V.; Pellikaan, W.F.; Salminen, J.P.; et al. Benefits of condensed tannins in forage legumes fed to ruminants: Importance of structure, concentration, and diet composition. *Crop. Sci.* 2019, 59, 861–885, doi:10.2135/cropsci2017.06.03697.512 B.

32. Kamaraj, ; Rahuman, A.; Elango, G.; Bagavan, A.; Zahir, A.A. Anthelmintic activity of botanical extracts against sheep gastrointestinal nematodes, *Haemonchus contortus*. *Parasitol. Res.* 2011, 109, 37–45, doi:10.1007/s00436–010-2218-y.

33. Mravčáková, ; Váradiová, Z.; Kopčáková, A.; Čobanová, K.; Grešáková, L.; Kišidayová, S.; Babják, M.; Dolinská, M.U.; Dvorožňáková, E.; Königová, A.; et al. Natural chemotherapeutic alternatives for controlling haemonchosis in sheep. *BMC Vet. Res.* 2019, 15, 302, doi:10.1186/s12917-019-2050-2.

34. Oliveira Santos, ; Ponce Morais Cerqueira, A.; Branco, A.; Batatinha, M.J.M.; Borges Botura, M. Anthelmintic activity of plants against gastrointestinal nematodes of goats: A review. *Parasitology* 2019, 146, 1233–1246, doi:10.1017/S0031182019000672.

35. Hoste, ; Torres-Acosta, J.F.J.; Sandoval-Castro, C.A.; Mueller-Harvey, I.; Sotiraki, S.; Louvandini, H.; Thamsborg, S.M.; Terrill, T.H. Tannin containing legumes as a model for nutraceuticals against digestive parasites in livestock. *Vet. Parasitol.* 2015, 312, 5–17, doi:10.1016/j.vetpar.2015.06.026.

36. Trejo, Características del medio físico de la selva baja caducifolia de México. *Invest. Geogr.* 1999, 39, 40–52.

37. Rzedowski, El endemismo en la flora fanerogámica mexicana: Una apreciación analítica preliminar. *Acta Bot. Mex.* 1991, 15, 47–64.

38. Leirana-Alcocer, L.; Hernández-Betancourt, S.; Salinas-Peba, L.; Guerrero-González, L. Cambios en la estructura y composición de la vegetación relacionados con los años de abandono de tierras agropecuarias en la selva baja caducifolia espinosa de la reserva de Dzilam, Yucatán. *Polibotánica* 2009, 27, 53–70.

39. Trejo, Las selvas secas del Pacífico Mexicano. In *Diversidad, Amenazas y Áreas Prioritarias Para la Conservación de Las Selvas Secas Del Pacífico de México*; Ceballos, G., Martínez, L., García, A., Espinoza, E., Creel, J.B., Dirzo, R., Eds.; Fondo de cultura económica—CONABIO: Ciudad de México, México, 2010; pp. 41–51.

40. Ancona, J.; Ruenes-Morales, R.; Huchim-Herrera, J.; Montañez-Escalante, P.I.; González-Iturbe, J.A. Woody species structure, diversity and floristic affinities in seasonally dry forest in the Uxmal archeological zone. *Trop. Subtrop. Agroecosyst.* 2019, 22, 755–767.

41. Gutiérrez, ; Zamora, P. Especies leñosas de la selva baja caducifolia de Xmatkuil, Yucatán, México. *Forestal Veracruzana*. 2012, 14, 9–14.

42. Flores, ; Durán, R.; Ortiz, J. Comunidades vegetales terrestres. In *Biodiversidad y Desarrollo Humano en Yucatán*; Durán, R., Méndez, M., Eds.; CICY, PPD-FMAM, CONABIO, SEDUMA: Mérida, México, 2010; pp. 125–129.

43. Ortíz-Ocampo, I.; Sandoval-Castro, C.A.; González-Pech, P.G.; Mancilla-Montelongo, G.; Ventura-Cordero, J.; Castañeda-Ramírez, G.S.; Tun-Garrido, J.; Torres-Acosta, J.F.J. Seasonal variation in the bromatological composition and polyphenol content of the leaves of *Gymnopodium floribundum* Rolfe from a tropical deciduous forest. in preparation.

44. Arellano, J.S.; Flores, J.S.; Tun-Garrido, J. Nomenclatura, Forma de Vida, Uso, Manejo y Distribución de las Especies Vegetales de la Península de Yucatán. Fascículo No. 20. *Etnoflora Yucatanense*; Facultad de Medicina Veterinaria y Zootecnia: Mérida, México, 2003; 320p.

45. Ayala-Burgos, ; Cetina-Góngora, R.; Capetillo-Leal, C.M.; Zapata-Campos, C.; Sandoval-Castro, C.A. Composición Química-Nutricional de Árboles Forrajeros. In *Compilación de Análisis de Laboratorio de Nutrición de la Facultad de Medicina Veterinaria y Zootecnia de la Universidad Autónoma de Yucatán*; Universidad Autónoma de Yucatán: Mérida, México, 2006.

46. González-Pech, ; Ventura-Cordero, J.; Ortiz-Ocampo, G.; Jaimez-Rodríguez, P.; Tun, J.; Sandoval-Castro, C.; Torres-Acosta, F. *Plantas Consumidas por Ovinos y Caprinos en la Selva Baja Caducifolia de Yucatán. Guía ilustrada*; Colofón ediciones; Universidad Autónoma de Yucatán: Mérida, México, 2017; 76p.

47. Ortiz-Domínguez, A.; Ventura-Cordero, J.; González-Pech, P.G.; Torres-Acosta, J.F.J.; Capetillo-Leal, C.M.; Sandoval-Castro, C.A. Nutritional value and in vitro digestibility of legume pods from seven tres species present in the tropical deciduous forest. *Trop. Subtrop. Agroecosyst.* 2017, 20, 505–510.

48. Tainton, M. The ecology of the main grazing lands of South Africa: The savanna biome. In *Veld Management in South Africa*; Tainton, N.M., Ed.; University of Natal Press: Pietermaritzburg, South Africa, 1999; pp. 23–53.

49. Retama-Flores, ; Torres-Acosta, J.F.J.; Sandoval-Castro, C.A.; Aguilar-Caballero, A.J.; Cámara-Sarmiento, R.; Canul-Ku, H.L. Maize supplementation of Pelibuey sheep in a silvopastoral system: Fodder selection, nutrient intake and resilience against gastrointestinal nematodes. *Animal* 2012, 6, 145–153, doi:10.1017/S175173111001339.

50. Gárate-Gallardo, ; Torres-Acosta, J.F.J.; Aguilar-Caballero, A.J.; Sandoval-Castro, C.A.; Cámara-Sarmiento, R.; Canul-Ku, H.L. Comparing different maize supplementation strategies to improve resilience and resistance against gastrointestinal nematode infections in browsing goats. *Parasite* 2015, 22, 19, doi:10.1051/parasite/2015019.

51. Pichersky, ; Lewinsohn, E. Convergent evolution in plant specialized metabolism. *Annu. Rev. Plant. Biol.* 2011, 62, 49–66, doi:10.1146/annurev-arplant-042110-103814.

52. Dixon, A.; Strack, D. Phytochemistry meets genome analysis, and beyond. *Phytochemistry* 2003, 62, 815–816, doi:10.1016/s0031-9422(02)00712-4.

53. Neilson, H.; Goodger, J.Q.D.; Woodrow, I.E.; Møller, B.L. Plant chemical defense: At what cost? *Trends Plant Sci.* 2003, 18, 250–258, doi:10.1016/j.tplants.2013.01.001.

54. Hackmann, J.; Spain, J.N. Invited review: Ruminant ecology and evolution: Perspectives useful to ruminant livestock research and production. *J. Dairy Sci.* 2010, 93, 1320–1334, doi:10.3168/jds.2009-2071.

55. Saarinen, The Palaeontology of Browsing and Grazing. In *The Ecology of Browsing and Grazing* II, 2nd ed.; Gordon, I.J., Prins, H.H.T., Eds.; Springer: Cham, Switzerland, 2019; pp. 5–59.

56. Mlambo, ; Marume, U.; Gajana, C.S. Utility of the browser's behavioural and physiological strategies in coping with dietary tannins: Are exogenous tannin-inactivating treatments necessary? *S. Afr. J. Anim. Sci.* 2015, 45, 441–451, doi:10.4314/sajas.v45i5.1.

57. Villalba, J.; Costes-Thiré, M.; Ginane, C. Phytochemicals in animal health: Diet selection and trade-offs between costs and benefits. *Proc. Nutr. Soc. USA* 2017, 76, 113–121, doi:10.1017/S0029665116000719.

58. Starkey, A.; Pugh, D.G. Internal Parasites of Sheep, Goats and Cervids. In *Sheep, Goat and Cervid Medicine*, 3rd ed., Pugh, D.G., Baird, A.N., Edmonson, M.A., Passler, T., Eds.; Elsevier: Amsterdam, The Netherlands, 2020; pp. 97–117.

59. Zajac, M.; Garza, J. Biology, Epidemiology, and Control of Gastrointestinal Nematodes of Small Ruminants. *Vet. Clin. N. Am. Food Anim. Pr.* 2020, 36, 73–87, doi:10.1016/j.cvfa.2019.12.005.

60. Torres-Acosta, F.J.; Jacobs, D.E.; Aguilar-Caballero, A.J.; Sandoval-Castro, C.A.; May-Martínez, M.; Cob-Galera, L.A. The effect of supplementary feeding on the resilience and resistance of browsing Criollo kids against natural gastrointestinal nematode infections during the rainy season in tropical México. *Vet. Parasitol.* 2004, 124, 217–238, doi:10.1016/j.vetpar.2004.07.009.

61. Torres-Acosta, F.J.; Hoste, H. Alternative or improved methods to limit gastro-intestinal parasitism in grazing sheep and goats. *Small Rum. Res.* 2008, 77, 159–173, doi:10.1016/j.smallrumres.2008.03.009.

62. Mavrot, ; Hertzberg, H.; Torgerson, P. Effect of gastro-intestinal nematode infection on sheep performance: A systematic review and meta-analysis. *Parasit. Vectors.* 2015, 8, 557, doi:10.1186/s13071-015-1164-z.

63. O'Connor, J.; Walkden-Brown, S.W.; Kahn, L. Ecology of the free-living stages of major trichostrongylid parasites of sheep. *Vet. Parasitol.* 2006, 142, 1–15, doi:10.1016/j.vetpar.2006.08.035.

64. Van Dijk, ; de Louw, M.D.E.; Kalis, L.P.A.; Morgan, E.R. Ultraviolet light increases mortality of nematode larvae and can explain patterns of larval availability at pasture. *Int. J. Parasitol.* 2009, 39, 1151–1156, doi:10.1016/j.ijpara.2009.03.004.

65. Hutchings, ; Milner, J.; Gordon, I.; Kyriazakis, I.; Jackson, F. Grazing decisions of Soay sheep (*Ovis aries*) on St. Kilda: A consequence of parasite distribution? *Oikos* 2002, 96, 235–244.

66. Fox, J.; Marion, G.; Davidson, R.S.; White, P.C.L.; Hutchings, M.R. Modelling parasite transmission in a grazing system: The importance of host behavior and immunity. *PLoS ONE* 2013, 8, e77996, doi:10.1371/journal.pone.0077996.

67. Hutchings, R.; Judge, J.; Gordon, I.J.; Athanasiadou, S.; Kyriazakis, I. Use of trade-off theory to advance the understanding of herbivore-parasite interactions. *Mamm. Rev.* 2006, 36, 1–16, doi:10.1111/j.1365-2907.2006.00080.x.

68. Vlassoff, Biology and population dynamics of the free living stages of gastrointestinal nematodes in sheep. In Control of Internal Parasites of Sheep; Ross, A.D., Ed.; Lincoln College: Lincoln, UK, 1982; pp. 11–20.

69. Tontini, F.; Poli, C.H.; Bremm, C.; de Castro, J.M.; Fajardo, N.M.; Sarout, B.N.; Castilhos, Z.M. Distribution of infective gastrointestinal helminth larvae in tropical erect grass under different pasture type for lambs. *Trop. Anim. Health Product.* 2015, 47, 1145–1152, doi:10.1007/s11250-015-0841-4.

70. Tontini, F.; Poli, C.H.; Hampel, V.S.; Fajardo, N.M.; Martins, A.A.; Minho, A.P.; Muir, J.P. Dispersal and concentration of sheep gastrointestinal nematode larvae on tropical pastures. *Small Rum. Res.* 2019, 174, 62–68, doi:10.1016/j.smallrumres.2019.03.013.

71. Jaimez-Rodríguez, R.; González-Pech, P.G.; Ventura-Cordero, J.; Brito, D.R.B.; Costa-Junior, L.M.; Sandoval-Castro, C.A.; Torres-Acosta, J.F.J. The worm burden of tracer kids and lambs browsing heterogeneous vegetation is influenced by strata harvested and not total dry matter intake or plant life form. *Trop. Anim. Health Prod.* 2019, 51, 2243–2251, doi:10.1007/s11250-019-01928-9.

72. Stear, J.; Singleton, D.; Matthews, L. An evolutionary perspective on gastrointestinal nematodes of sheep. *J. Helminthol.* 2011, 85, 113–120, doi:10.1017/S0022149X11000058.

73. Poulin, Are there general laws in parasite ecology? *Parasitology* 2007, 134, 763–776, doi:10.1017/S0031182006002150.

74. Morrill, ; Dargent, F.; Forbes, M.R. Explaining parasite aggregation: More than one parasite species at a time. *Int. J. Parasitol.* 2017, 47, 185–188, doi:10.1016/j.ijpara.2016.11.005.

75. Torres-Acosta, F.J.; González-Pech, P.G.; Chan-Pérez, J.I.; Sandoval-Castro, C.A.; Estrada-Reyes, Z.M.; Mendoza-de-Gives, P. Experiencias en el control alternativo de nematodos gastrointestinales de pequeños rumiantes domésticos en México. In *Avances en el Estudio de Helmintos Parásitos*; Ortega-Pierres, M.A., Morales-Monto, J., Eds.; Editorial UNAM: Ciudad de México, México, 2014; pp. 205–241.

76. Torres-Acosta, J.F.J.; Hoste, ; Sandoval-Castro, C.A.; Torres-Fajardo, R.A.; Ventura-Cordero, J.; González-Pech, P.G.; Mancilla-Montelongo, M.G.; Ojeda-Robertos, N.F.; Martínez-Ortiz-de-Montellano, C. The art of war against gastrointestinal nematodes in sheep and goat herds of the tropics. *Revista Acadêmica Ciênc. Animal.* 2019, 17, 39–46.

77. Coop, L.; Holmes, P.H. Nutrition and parasite interaction. *Int. J. Parasitol.* 1996, 26, 951–962, doi:10.1016/s0020-7519(96)80070-1.

78. Bishop, C. A consideration of resistance and tolerance for ruminant nematode infections. *Front. Genet.* 2012, 3, 168, doi:10.3389/fgene.2012.00168.

79. Ríos, ; Riley, J. Preliminary studies on the utilization of the natural vegetation in the henequen zone of Yucatán for the production of goats. I. Selection and nutritive value of native plants. *Trop. Anim. Health Prod.* 1985, 10, 1–10.

80. González-Pech, G.; Torres-Acosta, J.F.J.; Sandoval-Castro, C.A.; Tun-Garrido, J. Feeding behaviour of sheep and goats in a deciduous tropical forest during the dry season: The same menu consumed differently. *Small Rumin. Res.* 2015, 133, 128–134, doi:10.1016/j.smallrumres.2015.08.020.

81. Ventura-Cordero, ; González-Pech, P.G.; Torres-Acosta, J.F.J.; Sandoval-Castro, C.A.; Tun-Garrido, J. Sheep and goat browsing a tropical deciduous forest during the rainy season: Why does similar plant species consumption result in different nutrient intake? *Anim. Prod. Sci.* 2019, 59, 66–72, doi:10.1071/AN16512.

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